Quiet, clean and efficient buses in Twente

Final Report

Region Twente

October 2014

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SAMENVATTING

Innovatie in bussen voor openbaar vervoer is van belang om een bijdrage te leveren aan de (inter)nationale energie besparingsdoelstellingen, om de luchtkwaliteit (zeker in binnensteden) zo weinig mogelijk negatief te beïnvloeden, om de kwaliteit van openbaar vervoer optimaal en de producerende industrie vitaal te houden. Het huidige Nederlandse concessiestelsel mist een natuurlijke innovatieprikkel. Het toenmalige Ministerie van Verkeer en Waterstaat (nu Infrastructuur en Milieu) heeft daarom eind 2007 een subsidie beschikbaar gesteld voor 'pilotprojecten openbaar vervoer per bus'.

De gemeente Enschede wilde voor de na de vuurwerkramp van 2000 herbouwde wijk Roombeek 'duurzaam' busvervoer aanbieden.

Een aantal partijen waaronder de gemeente Enschede had zich op Europese schaal al verenigd met als doel diesel gevoede, serieel hybride stadsbussen te ontwikkelen op weg naar emissieloos openbaar vervoer.

Onder leiding van Regio Twente, het Twentse bestuurslichaam dat onder andere in de regio verantwoordelijk is voor het openbaar vervoer, heeft een aantal partijen een projectvoorstel ingediend met het doel subsidie te verwerven en zo in staat te zijn om twee pilotbussen te ontwikkelen en onder praktijkomstandigheden in Enschede te testen.

Het projectvoorstel is door het ministerie gehonoreerd en AgentschapNL (nu Rijkswaterstaat) is aangewezen om het project te begeleiden. Regio Twente heeft (in nauwe samenwerking met de gemeente Enschede en met DHV (nu Royal HaskoningDHV) als managing consultant) de eindverantwoordelijkheid voor het project op zich genomen. Connexxion, in de projectperiode uitvoerder van de vervoersconcessie in Twente, was betrokken als gebruiker van de pilotbussen. De voertuigen zouden worden gebouwd door VDL, Vossloh Kiepe en een Engelse groep die een vliegwiel met besturing zou leveren voor de energieopslag. In de ontwerpfase is ervoor gekozen de energieopslag alleen in supercondensatoren te doen in plaats van in een combinatie van een vliegwiel, accu's en supercondensatoren. Uit modelberekeningen bleek dat het met een realistisch pakket supercondensatoren mogelijk was en bovendien bleek dat de ontwikkeling van het vliegwiel voor deze specifieke toepassing niet in de voorgenomen tijd mogelijk was. Om de ontwikkelingen in het project op een aantal aspecten te monitoren en de technologie ook regionaal te verankeren is de Universiteit van Twente gevraagd te participeren.

Voor het kostbare en langlopende project is een projectorganisatie opgezet en een werkwijze afgesproken die het mogelijk heeft gemaakt met de inbreng van alle betrokken partijen zowel de ontwikkelings- als de testperiode goed te doorlopen. De werkwijze liet ruimte voor verschillende opvattingen en inzichten, maar is ook geschikt gebleken om knelpunten uit de weg te ruimen en het project tot een goed einde te brengen.

Het is aangetoond dat met een goede aanpak experimentele voertuigen kunnen worden gebouwd die in de praktijk betrouwbaar ingezet kunnen worden en zich goed staande kunnen houden in een vloot 'bewezen' bussen. De brandstofbesparing die een belangrijk doel van de innovatie was is niet gerealiseerd. Duidelijk is dat het hogere gewicht van de pilotbussen hier een belangrijke oorzaak van was. Een tweede reden is dat alleen de aandrijving is aangepakt en dat andere energiegebruikers samen zeker niet minder zijn gaan gebruiken. De (uitlaat)emissies zijn niet gemonitord. Harde uitspraken hierover zijn dan ook niet mogelijk. Wat geluid betreft is er sprake van een diffuus beeld: er is geen referentie bepaald. Wel is duidelijk geworden dat het geluid (en de trillingen) van de bussen in de eerste fase van de tests

aanleiding was tot klachten van omwonenden. Modificatie van in- en uitlaatkanaal heeft de klachten weggenomen. Een observatie is dat de aard van het geluid veranderd is door het gebruik van een viercilinder dieselmotor in plaats van de gebruikelijker zescilinder en door het bedrijven van deze motor op enkele constante toerentallen in plaats van een met de snelheid en het gevraagde vermogen wisselend toerental. Het objectiveren en zo vergelijkbaar maken van geluid gegeven deze invalshoeken is echter niet mogelijk. Het met uitgeschakelde dieselmotor aankomen en vertrekken bij elke halte is ontegenzeglijk een voordeel.

Een misschien niet verrassende, maar wel belangrijke uitkomst van de onderzoeken onder reizigers, omwonenden en chauffeurs is dat zij vooral naar de voertuigen keken als vervoermiddel en dat de innovatiedoelstellingen gericht op brandstofverbruik en emissies voor hun niet voorop stonden. Voor de onderhoudstechnici lag dit anders: vanuit hun professie waren zij meer geïnteresseerd in de 'onderhuidse' innovaties en waren zij tevreden met de betrouwbaarheid en de bereikbaarheid van de te onderhouden techniek.

SUMMARY

Innovation in public transportation busses is relevant for a contribution to (inter)national energy conservation targets, in order to prevent atmospheric pollution (especially in cities), to guarantee high quality public transportation and to keep the industry vital. The Dutch concession system lacks natural incentives for technological innovation. The Ministry, responsible for transportation therefore offered a subsidy (late 2007) for 'pilot projects in public transportation by bus'.

The Municipality of Enschede wished to provide the district 'Roombeek' – rebuilt after the 2000 fireworks tragedy – with sustainable public bus transportation.

A group of organizations, including the Municipality of Enschede had united on a European scale with the purpose of developing diesel fed, serial hybrid city busses as a step towards zero emission public transportation.

With region Twente – the regional government responsible among others for public transportation – in the lead, a group of organizations offered the Ministry a proposal to obtain a subsidy which would enable them to develop two pilot busses and to test them under operational conditions in Enschede.

The proposal was selected by the Ministry and the government agency RWS (at that time 'AgentschapNL) was appointed to represent the Ministry in the project. Region Twente (in close cooperation with the municipality Enschede and supported by DHV (now Royal HaskoningDHV) as managing consultant took the responsibility for the project. Connexxion, the executing transportation company in Twente participated as user of the pilot busses. Design, development and providing of the vehicles was in the hands of VDL, Vossloh Kiepe and a development group in the UK that could supply a flywheel with control system as a part of the energy storage system. In the design phase it was decided to use only supercaps for storage (instead of using a combination of a flywheel with accumulators and supercaps) as model calculations showed this was a viable option and because at the same time it showed that development of the flywheel for this specific application would not be possible in the timeframe available in this project. For specific monitoring activities and in order to absorb the innovation in the region the University of Twente was invited to participate.

For the costly and long project a project organization was set up and a process was designed which made it possible to value the input of all parties involved to optimize the development and testing activities. All views and experience could be input for the development and for all issues that were encountered thorough discussions were possible and the cooperation stayed constructive until the end.

In the project it was demonstrated that with the approach of the cooperating parties pilot vehicles can be made that prove reliable in practice and that can be operated in combination with 'regular' busses.
Fuel saving which was one of the key targets of the project has not materialized. It is clear that the inevitable weight increase was one of the main reasons. Also the project focused on propulsion while all other energy consumption may well have increased.

The (exhaust) emissions have not been monitored. The results and or perspective can therefore not be quantified. Noise production shows a mixed result. For one there was no reference defined. It became clear, however, that noise and vibrations of the hybrids gave rise to complaints from inhabitants of Enschede. Redesign of the inlet and outlet channels of the diesel engine stopped the complaints. An observation is that the character of the noise is different from that of the regular diesel busses because in

the hybrids 4-cylinder engines were used instead of the more common 6-cylinders and they were used at various fixed RPM's instead of at variable speed, changing with speed and required power. An objective comparison of the noise production of both types of busses is as good as impossible. Coming to a halt and accelerating from the bus stops with the diesel engine shut off.

An important conclusion from the stakeholder surveys which may not come as a surprise is that te passengers, inhabitants of Enschede and drivers see the vehicles as a means of transport (or working place). Fuel saving and sustainable nature are not their primary interest. The maintenance technicians are professionally interested in the technological innovations. They were positive about the reliability and about the way the technology could be reached for maintenance.

1 INTRODUCTION

Early this century the so-called concession system was introduced in Dutch public transportation and therefore also in public transportation by buses. Up to that time this type of transport had been a service provided by public authorities themselves. In the new system the authorities are still responsible for good public transport but the operational work is performed by private parties (in competition) under contracts. The aim of the change of system was to improve the service while at the same time optimizing the efficiency.

Later on it was discovered that the system does not incorporate effective incentives for innovations in the vehicle. These were necessary not only to ensure the overall transportation quality, but also in order to meet environmental demands and to keep the bus industry competitive. The (inter)national target to reduce greenhouse gas emissions with 30% in 2020 relative to 1990 requires a contribution by the transport sector. Inevitably innovations in vehicles have to be introduced for this purpose.

To stimulate developments the Dutch Government created a program in 2008 ('Pilot projects in public transportation by bus') with the aim of stimulating innovation in buses.

In the Municipality of Enschede a dramatic accident at a fireworks depot destroyed an entire district (Roombeek) in 2000. Since then the area has been very attractively renewed. The inhabitants were given a central role in the process. The municipality wished to also introduce public transportation at a high level of quality. Not only the transport quality should be extraordinary, but also environmental aspects should be of a high standard. Especially concerning fuel consumption, emissions and noise. This would not only provide Roombeek with an advanced public bus system, it would also contribute to meeting the cities' environmental and technological ambitions. The regional governmental organization 'Region Twente' is the organization responsible for public transportation in Enschede and was very willing to cooperate.

A consortium was formed to take the next step: develop and test an innovative bus for public transport in Enschede. The consortium was a part of an international group previously formed in order to develop the new bus technology on an international scale. Part of this group decided to grab the Dutch opportunity.

The region Twente and the municipality Enschede took the responsibility for the project. VDL and Vossloh Kiepe combined forces to develop the bus, Connexxion, operating the public transport buses in Twente was available to adopt the 'prototypes' in the regional fleet. The University of Twente was approached to monitor various aspects and Royal HaskoningDHV as managing consultant. Government agency AgenschapNL formed the interface with the national Government and the other projects in the program as well as with the overall monitoring program.

The plan for the 'quiet, clean and efficient buses in Twente' operationally aimed at developing two highly innovative buses (so-called 'serial-hybrids') and testing and optimizing these in practice in Enschede during a two year period.

At the time the plan was developed the central target was to halve the fuel consumption compared to current bus types and to limit the emissions especially of nitrogen oxides, fine particles and noise.

Key technological parameters were to be monitored in order to be able to evaluate the results versus the targets and also to form a basis for prediction of future improvements. In the plan for Enschede it was incorporated that the experiences of travelers, drivers and inhabitants of Enschede were to be studied.

In a monitoring and evaluation program to be defined by the Ministry some parameters would be determined uniformly for all the buses in the national program. The goal of this was to generate data for comparison of the tested vehicle technologies. As a part of the overall program AgentschapNL therefore intended to appoint an expert organization for overall monitoring and evaluation of all projects including ‘roller bank simulation’ tests for more accurate determination of the emissions and comparison with the performance of EEV buses. At the time of publishing this report no results of the overall monitoring have become available. For specific emissions no monitoring was foreseen as a part of the project. The performance evaluation was to be based on the figures to be generated by the overall monitoring.

Key elements defined in the program:
25% reduction of emissions compared to an EEV bus
50% reduction of the CO_2 emission compared to an EEV bus (‘tank-to-wheel’)
2 identical prototypes
Minimum annual distance covered: 10 000km
Minimum test duration: 2 years
Total project duration: maximum 4 years
Innovative technology

2 THE PROJECT

2.1 The plan

In the project as it was proposed the outline was to develop, build and test (under operational conditions) two innovative prototype buses. The buses were to be based on a proven design with a 'traditional' diesel driveline and to demonstrate minimal fuel consumption and emissions (CO_2, NO_x and particles, CO, HC, as well as noise). The target for the reduction of fuel consumption and CO_2 emissions was 50% (tank – to – wheel) and for the other airborne emissions 25%, both relative to the EEV (Enhanced Environmentally Friendly) standards. For noise no quantitative target was set. In the program two options for the development stage of the vehicles were defined: 'alpha' or 'proof in practice' and 'beta' or 'pre-market'. The buses for this project were 'alpha' vehicles.

Richtlijn	naam	met ingang van	CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	deeltjes (g/kWh)	rook (m^{-1})
88/77	Euro 0	1988/1990	11,2	2,4	14,4	-	-
91/542	Euro I	01/07/1992	4,5	1,1	8,0	0,36	-
91/542	Euro II	01/10/1995	4,0	1,1	7,0	0,15	-
1999/96	Euro III	01/10/2000	2,1	0,66	5,0	0,10 (of 0,13)	0,50
1999/96	Euro IV	01/10/2005	1,5	0,46	3,5	0,02	0,50
1999/96	Euro V	01/10/2008	1,5	0,46	2,0	0,02	0,50
1999/96	EEV	01/11/2010	0,25	0,20	0,02	0,015	

Emission standards for 'type approval' of large diesel engines for heavy commercial vehicles

The essence was to demonstrate it is possible to develop an innovative bus, meeting all modern standards from the perspective of travelers, operators (including drivers and operational technicians) and those living where the buses are operated while at the same time drastically reducing fuel consumption as well as emissions to air and noise.

The consortium chose diesel – electric, serial hybrid as the driveline technology to meet the targets. The motives were:

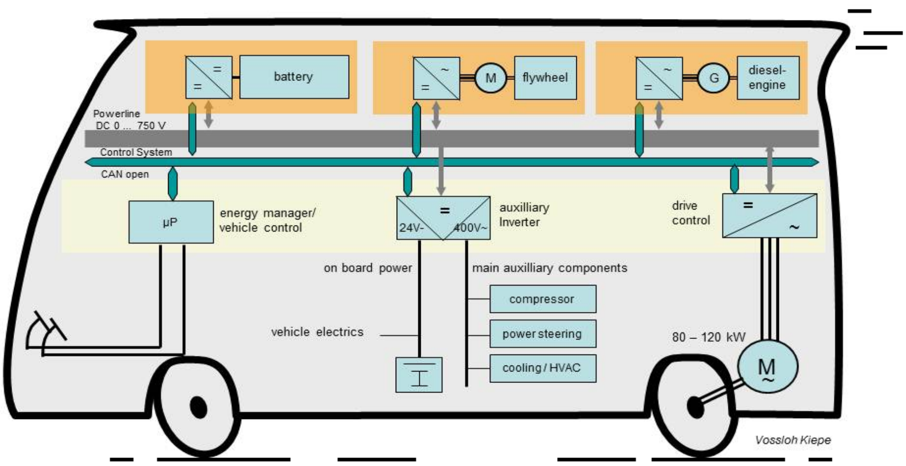
1. hybrid drives have been identified by the 'Platform Sustainable Mobility' as a very promising transition technology to sustainable public transport,
2. hybrid technology can be combined with recuperation of brake energy and is therefore very well suited for urban (public) transport,
3. serial hybrid technology provides options for increased comfort (smooth ride by using 'accelerate-by-wire', fully electric acceleration from bus stops, no gear change shocks or noise),
4. fuel saving also decreases CO_2 emissions therefore the technology contributes to not only limitation of 'oil-dependence' but also to climate protection,
5. economic perspective because fuel savings can compensate higher investments,
6. diesel based hybrids can be deployed without any change in infrastructure
7. a substantial fuel saving in (urban) public transport helps slowing down oil reserves depletion.

It was clear from the start that not only the core of the driveline was decisive for the achievements but also that optimizing energy efficiency in all energy using components of the bus would be required.

The technological innovations foreseen were:

- Use of a light weight basic vehicle,
- maximum recovery of brake energy,
- limited fuel consumption and emissions by optimizing operational rpm – torque combinations for the diesel engine,
- zero fuel consumption during stops by start – stop system,
- optimized energy storage system based on flywheel, supercapacitors and/or batteries to be engineered in the project,
- minimizing acceleration energy use through ‘accelerate by wire system’,
- maximize energy efficiency in driveline and auxiliaries,
- intelligent overall control system with GPS link.

It was not a part of the project targets to design an extra light weight vehicle. As the vehicle weight is an important factor in energy demand, studying the effects was seen as part of the project. The basics of the hybrid buses were to be the use of an existing lightweight VDL bus, driven by a compact electric motor driving the rear wheels through a differential in the rear shaft. The motor was to be controlled by a system based on trolley bus technology, optimized for low weight and energy use and high efficiency components. Also the control system was to use GPS information, combined with information on the specific route. The electric power was to be supplied by a high efficiency generator driven by a modern and light EEV diesel engine equipped with a start – stop system. The electric motor would provide all torque and power required for the driving in traffic. The diesel engine was to run intermittently with limited variation in load and RPM. Matching these two different modes of operation would be done by incorporating an intermediate storage system, also essential for the recovery of brake energy. It was aimed at using an innovative flywheel unit as the core of the energy storage system and to determine in the design phase whether incorporating batteries and/or supercapacitors would improve the performance without ‘overloading’ the bus by weight or the feasibility due to excessive costs.



Planned energy system of the hybrid bus

Targets:

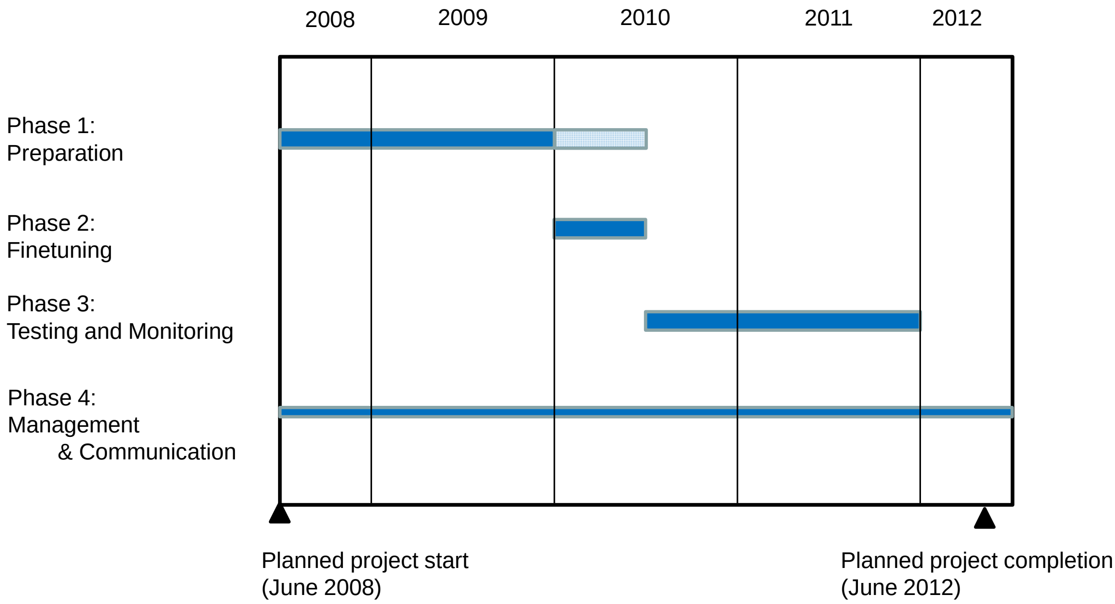
- *Important reduction of fuel consumption (50% compared to EEV) by combining:*
  - *brake energy recuperation,*
  - *application of a relatively small capacity diesel engine,*
  - *operation of the diesel engine near maximum energy efficiency and minimum emissions in stead of maximum torque or power,*
  - *application of start-stop system on the diesel engine,*
  - *optimization of energy consuming auxiliary systems and*
  - *advanced control system for optimal energy use using a.o. GPS and 'accelerate by wire'.*
- *Similar reduction of CO_2 emissions*
- *Related reduction of other exhaust emissions*
- *Reduced noise emissions because:*
  - *the diesel engine is not required to provide peak torque and power*
  - *the diesel engine is stopped at bus stops*
  - *the energy storage system supplies the power for initial acceleration at bus stops*
  - *short distance fully electric drive is possible*
- *More comfort for travelers and people living near bus routes (better driving characteristics, less noise, less emissions*
- *Expected improved business case for the transport operators in case of increased number of buses through decreasing extra investments and substantial reduction of fuel consumption.*

Key targets for reduction of fuel consumption and emissions

2.2 The planning

Before the project start, a project plan was developed, the outline specifications of the vehicles were defined, candidates for key components were selected (and approached) and critical components (in terms of supply time) were identified.
According to the plan the vehicles would be designed and built in a first 'preparatory' phase, for which approximately 2 years were expected to be required including the support of the fine-tuning phase. In the project plan this was elaborated in much detail. It was expected to be a critical phase in which the demands would have to be finalized and the key design elements would have to be determined. Some components would require long delivery periods so they would have to be selected as early as possible (e.g. the bus bodies, the engines and the main motors/generators). In parallel with the end of the preparations a period of 6 months was foreseen for tests and fine-tuning after which the 18 months period for testing in practice and monitoring was foreseen.

Therefore the first steps would be definition and specification of the key components. Then the design, development and testing of the parts and subassemblies that VDL and Vossloh Kiepe were to supply followed after which overall assembly and 'shop testing' were foreseen. In this phase also training of the drivers and operational technicians was planned as well as formal approval by the transportation authorities. As the energy management system was to be optimized, the specific route in Enschede was to be characterized in detail.



Project Planning

In the fine-tuning phase it was planned that the vehicles would be operated on the selected route, but with the main purpose of dealing with initial weak spots and optimizing the innovative components. All support systems of Connexxion, VDL and Vossloh Kiepe were to be tuned for quick response in case of emergencies in order not to get a bad reputation before the real testing even started. In this phase it was planned to investigate the user experience. For these activities a total of approximately 6 months was planned.

After this initial testing in practice and fine-tuning of the vehicles the real 18 months road testing period was scheduled. In this period four ‘ordinary buses’ and the two hybrids would service route 2 in Enschede in a ‘business-as-usual’ manner. Monitoring of fuel consumption and maintenance and repair activities would take place continuously; researching the attitudes of passengers, drivers and people living near the route were also scheduled in this phase. The evaluation and final reporting was defined as a 5 months step in this final phase.

Communication, management, coordination and intermediate reporting were defined as continuous activities. Overall the project was planned to be executed in 3 years and 10 months.

2.3 The budget

In the project as it was proposed for subsidy in the national program the budget was as presented in the table below:

Overview				
	Costs of staff	Add. costs	Total costs	Contribution
Region Twente	139933	103000	242933	202550
Mun. Enschede	142833	63500	206333	202550
Connexxion	163240	30000	193240	
DHV	195000	10000	205000	
University of Twente	87356	5300	92656	
Vossloh Kiepe	200000	600000	800000	200000
VDL	646500	297000	943500	200000
Total	1574862	1108800	2683662	
Overall total	2683662			
Subsidy (70%)	1878563			
remainder	805099 ↔			805099

Budget plan

The total budget required for the execution of the project was calculated as 2.68 million Euro. For funding Region Twente, Municipality Enschede, VDL and Vossloh Kiepe contributed some 200 000 Euro each. The balance was made with a substantial subsidy of almost 1.9 million Euro, awarded by the Dutch Government.

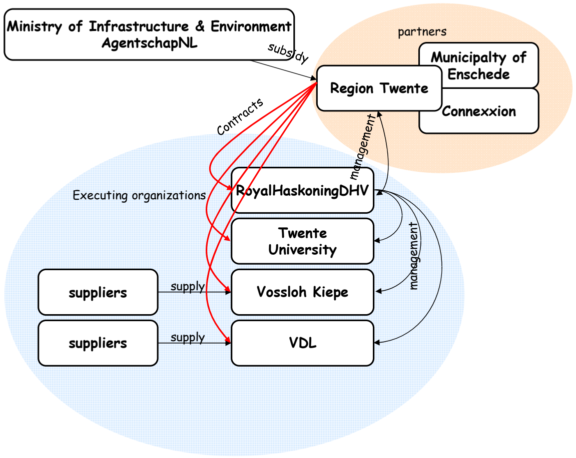
2.4 Future developments

The project was designed as a type alpha project. By the definition in the government program alpha projects aim at optimizing, testing and monitoring innovative technology. If successful, the next phase of the development would be ‘beta testing’. In this step - prior to real market introduction - production would be optimized and larger scale testing under practical conditions would show the final flaws to be dealt with before market introduction. It was considered that a successful alpha testing of the serial hybrids would create the momentum for market success of the technology and increased contribution to limiting the environmental impacts of urban public transport. The parties in the project were part of the network in Europe working on this development (including several cities). This was expected to be a great asset for the technology transfer.

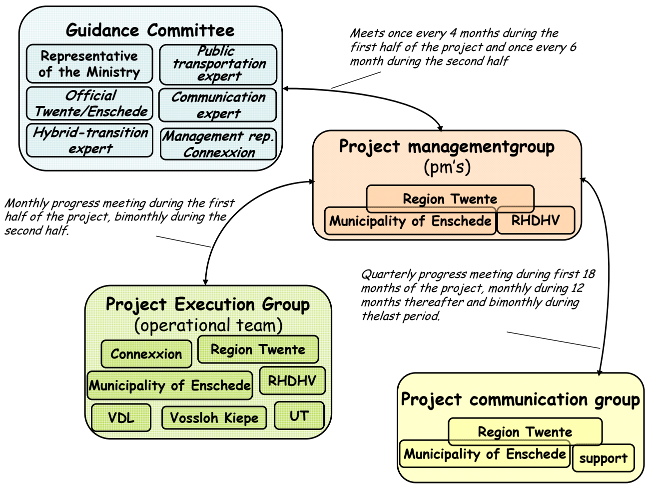
The two prototypes were estimated as too expensive for a sound business case. However, it was expected that the business case, based on TCO would be attractive after the foreseen beta phase. Key elements for this development would be the achieved fuel saving and the optimized production efficiency in the beta phase. If the foreseen limited weight and volume of the drivetrain was demonstrated it was expected that the drivetrain technology would be easily adapted to most diesel bus platforms. Therefore the overall contribution to fuel saving and emissions minimization had a substantial potential. It was also foreseen that in case of success the technology could be scaled down for application in 8,5m buses and up for articulated or double-articulated buses. The potential in Europe alone is substantial and globally even more than that.

2.5 The project organization

In the starting phase the cooperation between all parties involved in the project was as shown in below illustration. The initial project organizational structure is shown below.



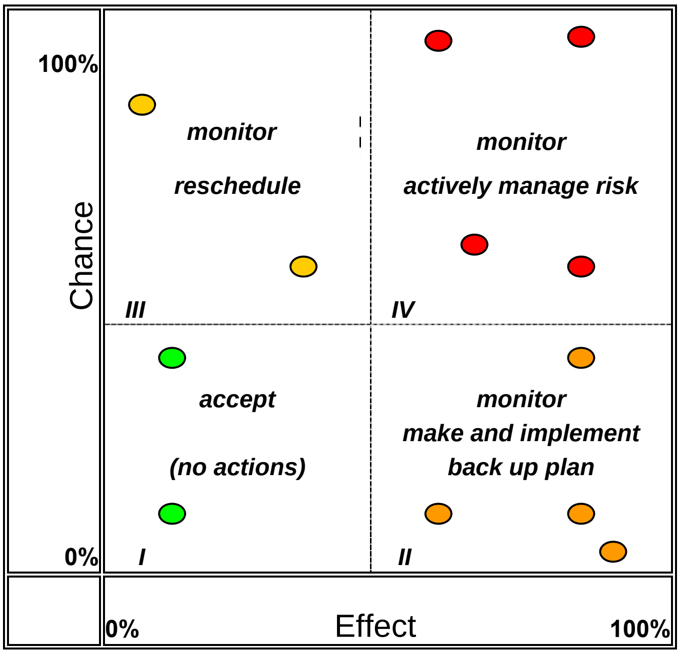
Parties involved and their project relations



Project organization structure

2.6 Foreseen risks

As a part of the project plan management of project risks was elaborated. Ex ante following the structure of 5 P's (Product, Price, Place, Promotion and People) potential risks were inventoried. Also for managing of risks a methodology was adapted by dividing the area covering the chance the risk manifests itself and the effect of the risk factor into four 'management sectors' as shown below. In the listing below for each risk it is indicated in which quadrant it was thought.



Four risk management sectors

Foreseen risks and proposed management:

Product:

1. Start – stop system on the diesel engine is not functioning as expected. (QII)
   Management:
   The system was to be developed in close cooperation with the engine manufacturer, which limits the chance of this risk occurring. Preparations had already started, increasing development time thereby limiting the risk. Various design steps for the development of the system were incorporated increasing the chances of success. Once the system would be approved it might cause diesel engine malfunctioning during the long term tests. This was to be covered by transferring the risk to the supplier in the final contract.
2. In the design and development stage the flywheel might show not to be the desired, reliable energy storage system. (QII)
   Management:
   The flywheel as energy storage in a bus to be tested in practice was promising but quite innovative. At the time of writing the project plan the specific units for this application were being tested. Parties involved in the development had a long track record in the application of fiber reinforced composites. The existing development stage and the experience of the producers were seen as limiting the project risk. On top of this various development steps for this component were foreseen in the project plan increasing control of the development and limiting the risk.

3. Insufficient performance of the control system. (QII)
   Management:
   Although less advanced, the control system was already being used in other buses. The risk was considered small and further mitigated by incorporating various development steps in the project plan. Both Vossloh Kiepe and the developers of the flywheel had many years of experience in development and building of control systems.
4. Problems in integrating multiple components. (QII)
   Management:
   As a developing partner in the project Vossloh Kiepe was considered to be specialized in the integration of hardware and software. The technological risks of complex integration were therefore thought low. However, the complexity of the multitude of project activities in a short time was considered ambitious for the coordination of the organizations in the project. The main perceived risk was that of delay. The tools available to confront this risk were high quality management and communication.
5. Availability of the buses due to failure. (QII)
   Management:
   Service was guaranteed 24/7 by the technology developers. A procedure to be followed in case of failure was to be developed before the practical tests. The project also incorporated spare buses in the Connexxion fleet to assure availability of bus service in case of failure of the hybrid(s).
6. Project targets not reached. (QII)
   Management:
   The project plan incorporated a thorough engineering phase, elaborate testing in preparation of the true tests, a 6 months period for fine-tuning as well as training of drivers and technicians. All relevant variables were to be controlled in a plan-do-check-act cycle to assure timely response to deviations. This could not guarantee results to be achieved but it did assure the maximum effort for this. In the monitoring program it would become manifest why, in case of not reaching the targets and how this should be addressed in further tests.

Price

7. Investments unexpectedly high. (QII)
   Management:
   The technology developing partners committed themselves to substantial investments in the project and could be seen as sufficiently strong to absorb financial deceptions. They were committed to the project plan and budget and to signing contracts on this if the subsidy would be awarded.

Place

8. Number of stops exceeds capacity of start-stop system. Q(II)
   Management:
   Negotiations with the engine supplier were engaged even before the project started. Normally the supplier guarantees a minimum number of starts the engine can endure. It was expected that the issue could be resolved for the specific route in Enschede. It might be a recurring issue for other use.

Promotion

9. Negative press coverage even before project start. (QII)
   Management:
   At the start of the project (or even before that moment) a project communication strategy is devised. It is elaborated in a communications execution plan in which all participants are well represented and to which the management of all cooperating parties is committed. Expertise e.g from the Guidance Committee is used. The communications team developes and maintains a good relationship with the

press and information on the project is frequently provided. The websites of the Region and the Municipality are well used in communication about the project.

People

10. Expectations too high or changing. Q(IV)
    Management:
    This can be considered as a major risk in the multiyear project, which may occur when political preferences/persons change after elections. Well managed communication and frequent updating about developments, results and issues are essential in the management of this risk. Making sure expectations are well matched to project developments is the key.

11. Negative attitude of primary stakeholders (drivers) in case of disappointing test results. Q(IV)
    Management:
    The image of the bus should be such that it is an honor to use or drive it. For this reason it is essential that the bus is very reliable and can be easily recognized as a top vehicle in the fleet. Also it is important that those directly involved in daily operations (drivers and technicians) are very well trained and regularly informed about developments. The University of Twente will be in close contact with these stakeholders in training, monitoring and communication.

12. Poor decision making in the project team causing project standstill. Q(II)
    Management:
    The project management structure is well designed. Day-to-day management has to further prevent this risk. The PMG plays a key role and the commitment of all parties involved in project execution is essential.

13. Planning control unsuccessful. Q(IV)
    Management:
    All steps in the project will as much as possible be substantiated in the project contracts. In case of delays partners and subcontractor will mobilize additional capacity to control this risk.

3 EVALUATING THE PROJECT

3.0 Introduction

In the final stage of the project the consortium looked back at the way the project has developed. The key questions to be answered were:

1. did the group of organizations executing the project cover all relevant fields in order to make the project successful?
2. was the project organization adequate and effective?
3. could the planning be followed?
4. were there any specific financial issues?
5. did the risks that were previewed and their management prove useful for project success?
6. were the consecutive stages in the process effective and efficient?
7. are the reasons for selecting the technology still valid?
8. Was the development of the two buses successful?
9. have the technological characteristics contributed to reducing fuel consumption and emissions
10. did technological monitoring activities - including the data analysis and interpretation - provide results useful for the project evaluation?

The first six questions cover the process, the last four deal with the contents and the main stakeholder groups.

In the following paragraphs first the way the program was executed is analyzed. In this analysis some of the events influencing the execution are described. After this the first six questions are discussed. In the next chapter the focus is on results found in the monitoring activities.

Essentially it was
demonstrated it is possible to develop an innovative bus, meeting all modern standards from the perspective of travelers, operators (including drivers and operational technicians) and those living where the buses are operated while at the same time reducing fuel consumption as well as emissions to air and noise.

The reductions in fuel consumption and emissions, set as the desired result of the project were, however, not quite realized.

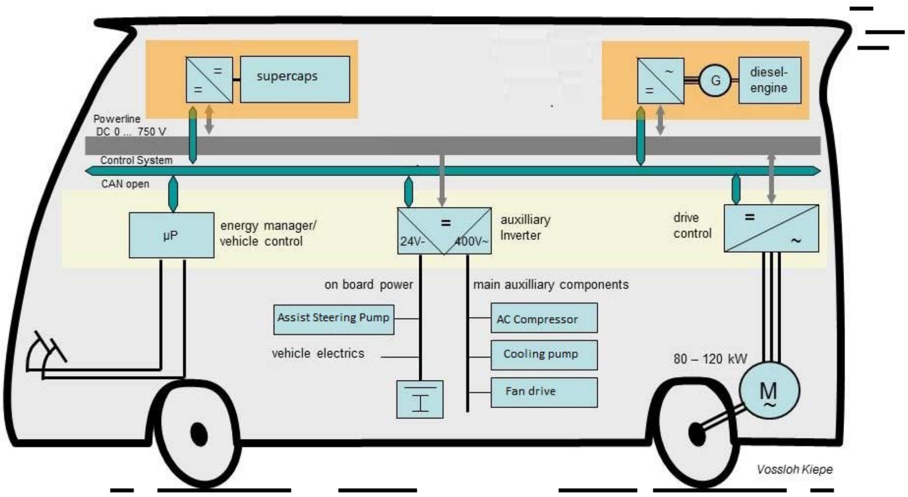
3.1 The plan

As planned two innovative prototype buses were developed, built and tested in practice in the project. The vehicles were based on the proven, inner city public transportation bus Citea of the participating bus manufacturer VDL.

The aims were not quite met, but not because of the quality of the plan or the execution thereof. It was impossible to meet all the targets using proven elements as building blocks for the buses which was required in order not to exceed the project duration and budget. A further discussion of the reductions achieved in the project is presented in the next chapter.

In all the design choices the desired reduction of fuel consumption and emissions were taken into consideration. As planned diesel – electric, serial hybrid was chosen as the driveline technology to meet the targets. The motives were as presented in the previous chapter. The findings on the viability of this driveline technology are discussed in the next chapter.

All technological principles and innovations mentioned in paragraph 2.1 were targeted in the preparatory phases. In all the design choices the desired reduction of fuel consumption and emissions were taken into consideration as described below. In the sketch some essentials are presented.



Implemented energy system of the hybrid bus

Light weight basic vehicle
Although the selected Citea is a modern design, it is not the lightest type of public transportation bus manufactured by VDL. When considering the potential weight increase of the serial hybrid compared to the straightforward diesel it was determined that the Citea would form a reliable and '*relatively light'* basis for the design. It was inevitable that an increase of the vehicle weight would rather cause an increase of fuel consumption and emissions. In this case the issue doubled: because of the loads caused by (the weight of) the extra equipment required for the hybrid driveline a heavier basic vehicle had to be chosen.

Maximum recovery of brake energy
Except in case of emergency all braking actions were done by reverse use of the electric drive train: the main motor was operated as a generator and the electric energy thus generated was stored in the super capacitors. Unfortunately there still is an acceleration – deceleration energy loss due to efficiency of the components and the energy required for control. Occasionally traditional brakes were used to stop the bus (emergency situations). Naturally this energy was not recovered.

Optimizing fuel consumption and emissions by the diesel engine
The fuel consumption and emissions of the diesel engine were reduced by operating it at optimal RPM. Perhaps the result can be further optimized if the engine is specially designed for this type of use in stead of for variable speeds. Within the scope of the project the options were limited to optimal use of a regular

diesel engine. Some of the result was achieved by the use of a somewhat smaller diesel engine (no peak demands) than the one that would be required for a none-hybrid drive.

Start – stop system
As a result of discussions with the manufacturer of the diesel engine it was allowed to use a start stop system on the diesel engine without limiting the guarantees. This prevented idling the diesel when the supercapacitors were sufficiently loaded.

Optimizing the (electric) energy storage
When the plan was written a preference existed for a flywheel as the core of the storage system. Developments in this field, however, were not such that the envisaged reliability of the buses could be guaranteed. Also it was feared that using the flywheel would take up too much space if placed in the engine compartment. Dealing with the gyroscopic reaction forces would require extra reinforcement of the bus bodies (weight increase and potential loss of reliability and/or serviceability), especially if placement on the roof would be required. In the design phase it was determined that a storage system based solely on supercapacitors could provide the required capacity and characteristics. Compared to the initial ideas of combining a flywheel, ‘regular’ batteries and supercapacitors in order to meet the requirements for power absorption, delivery and energy storage capacity this reduced energy losses especially since these capacitors have a relatively attractive output/input ratio. In these discussions the relevance of not ‘sacrificing’ seats was stressed repeatedly. Extra weight would up to a point not interfere with the primary functionality, but limiting passenger space certainly would.

Drive by wire
Using drive-by-wire technology makes control of the vehicle drive less dependent on driver behavior. This system was successfully introduced and it was demonstrated that it can be tuned such that driver demands are met, safety of the vehicle in traffic is not compromised and a contribution is given to fuel efficiency.

Maximum efficiency in driveline and auxiliaries
The driveline was designed as an assembly of existing components. Good quality was selected, but, as already mentioned above concerning the diesel engine, the electric motor/generator, the transmission and the energy storage were not specifically designed and optimized for this use. Eliminating the differential alone may well cut traction energy losses by 3 - 5%!

It was clear from the start that not only the core of the driveline would be decisive for the energy and emissions achievements but also that optimizing energy efficiency in all other energy using components of the bus would be required. Unfortunately in the design and engineering phase it was found that no suitable, energy efficient alternatives were available for the auxiliaries. In some of the major energy consuming sub-systems (e.g. heating and air-conditioning) only one or few options are available in the market. For many others (mostly driven by electric motors) high quality options could be found, but in general not exactly meeting the specs for power, size or capacity and not of an ‘automotive quality’. Especially the high voltage system (appr. 700V DC) limited the market to industrial drives, capable of many hours of reliable service under industrial conditions. These characteristics are quite different from those of specific automotive equipment. The project did not incorporate the time or capacities for special developments in this area.

Intelligent overall control system with GPS link
The overall control system developed consisted of the power control and the power conversion system, the system controlling the components and the software defining the behavior of the control system. Some

components and some auxiliary systems had their own control system. Where optimization was expected to be useful for reduction of energy use and emissions these decentral control systems were put under coordination of the overall system.

Vossloh Kiepe has many years of experience in electric drives for (trolley)busses and trams in developing the electrical and electronic systems as well as the software for the drive and control. Close cooperation with VDL assured optimal adaptation to the (electro)mechanical systems. As a remarkable innovation a GPS link was introduced. With this the control system can combine its position with known information about the stretch ahead. The bus 'knows' what is coming. Therefore it also has expectations of how much energy is required and whether or not the diesel engine has to run to feed the storage system. It is expected that once optimized these controls will be very promising for fully electric as well as for hybrid vehicles.

3.2 The planning

In the proposal it was expected that the project would start in August 2008 and would be finished by June 2012. Mainly by delayed project selection and financing arrangements and also by the lengthy process of finalizing the key contract between the parties cooperating in the project the official starting date was March 1 2009. Due to these delays the production planning had to be rearranged and the vehicles were completed and ready for driver training and fine-tuning in December 2010. The delayed project start and the required adaptation of the production planning, the decision making on an innovative axle (in the market an innovative rear axle became available and the technology suppliers opted for the introduction of that component; funding, however, was not possible) and the 'reorientation' on the energy storage system were the main reasons for the delay by a total of 7 months. Updating the software (changing the control strategy from torque control to speed control of the diesel engine) took place in April 2012. The final pilot of the busses under practical conditions was completed end of May 2013 instead of December 2011 as planned in the proposal. Final reporting took a long period and was finalized as a last step in the project in August 2014.

Phase 1: Preparation

The deadline for project proposals in the Government Program was end of April 2008. The proposal was also presented to the Evaluation Commission of the Ministry on July 2. Specific questions of the Commission focused on follow up and the destination of the buses after project completion.

The proposal was very well received and in August the Ministry announced the selection. However, the intent could only be officially announced in September and the final commitment could not be signed before October. The group of parties decided not to lose all this time and regular meetings of the Project Execution Group (PEG; on a monthly basis during the first years, bimonthly later on) were started on September 3. The first issues were to deal with the technical priorities (selection and procurement of critical components and dealing with the developments of the flywheels). Operationalizing the organization and arranging the project contracts were taken up. Especially the flywheel developments and the contracts proved to be time consuming. Flywheel developments in Britain had come to 'proof of principle' but further steps to 'everyday use quality' proved not feasible. The design team of Vossloh Kiepe and VDL managed to engineer a storage system based on supercapacitors alone and the option of applying flywheels was abandoned.

In the contracts the key issue was that VDL as well as Vossloh Kiepe were stretched on the project risks for their own part. Overall responsibility for the vehicles was unacceptable for either one of them. Region

Twente on the other hand was normally not in charge of technology development on a daily basis so taking the overall responsibility for the technology was not their logical option. After lengthy discussions one agreement between three parties was reached, acceptable for all three. In this agreement also payment schedules and the functional specifications of the buses were defined. This key contract was finalized in March 2009.

Fortunately this process did not have too much of a negative impact on the execution as the technology developers started the work and Region Twente was flexible in financing early procurement costs. March 1 2009 was the official starting date of the preparation phase of the project.

The relationship of Region Twente with Enschede Municipality was already clear as that between regional and local public authorities. Participation in the project as partners was only an extension of the existing relationship. Connexxion was the current transport company supplying all public transport for Region Twente. The role of Connexxion in the pilot project was simply adding specified tasks at a defined price to the existing contract. The University and (Royal Haskoning)DHV were participating for specified tasks under straightforward subcontracts with Region Twente as their employer.

In this early phase an unforeseen option for improvement was identified: ZF, a major European (automotive) transmission producer announced a new rear axle for electric drive buses. The axle was equipped with two electric motors combined with a planetary gear for each of the wheels. Incorporating this axle would introduce an extra potential reduction of fuel consumption and emissions and would also take up less space (especially in the engine compartment) than the central motor-differential combination. Unfortunately the extra costs could in this stage not be subsidized by the Government and without the subsidy the cost increase was too much for VDL, Vossloh Kiepe and the Region to bear. After weighing all pro's and con's and scrutinizing the options for financial support the use of this axle had to be dismissed.

In the meantime the definition of the buses was determined. This was mainly an interaction between Connexxion and VDL. This definition started with the Citea as a basic vehicle, equipped with a hybrid driveline and was expanded with the specifications for the Twente fleet.

After setting the real starting date the development of the buses was the critical line of activities. By far most of this work was done in cooperation between VDL and Vossloh Kiepe. On a regular (monthly) basis the developments, choices to be made and issues encountered were discussed in the PEG. The great advantage was that many development aspects were shared over all participating parties and that there was a common commitment to the vehicles playing such a key role in the project. Also all development dilemmas were shared instead of being just an issue for the developers with the others as bystanders.

Developing a communication and a monitoring plan was less critical. It was decided that effective communication was difficult to plan much in detail as a strategy and a plan because it would depend very much on events in the project and their timing. It was therefore decided that it would be controlled from the PEG and be as closely related to project development as possible. In this phase preparations for activities for the 'launch' of the buses were performed: a leaflet was prepared, a small scale fair for the 'official start' event, at which all participants in the project would have the opportunity to present themselves was prepared and a press release was made. Also the stickers for the outside of the buses were designed and an animation film explaining the special character of the buses was prepared for the public site: www.lijn2gaatgroen.nl.

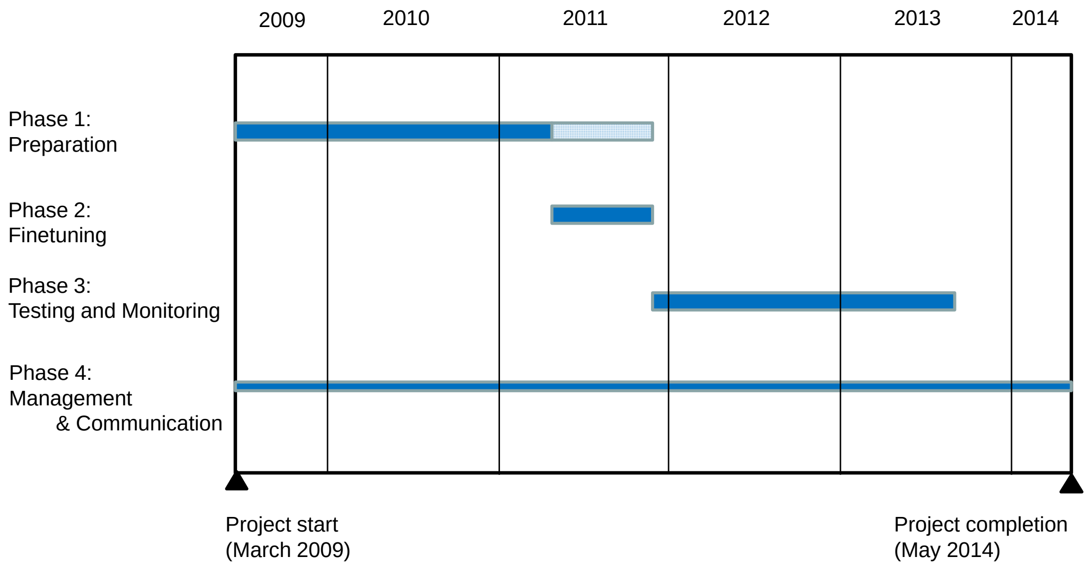
The monitoring preparations were complicated by the fact that the overall program monitoring was not defined in this stage. Also it was not a defined activity in the program and in the proposal only a limited budget was reserved counting on the overall program monitoring to define the required data/information and to provide the means if required. As the overall program monitoring did not really substantiate during the project period it was not possible to derive conclusions on some of the essential targets of the project and the program. Fortunately this did not interfere with project progress or the experiences gained by the participating organizations.

As a result no extra provisions for monitoring (e.g. for monitoring of the energy use by specific components such as heating or air conditioning) were entered in the specs of the buses. It was determined that the fuel consumption could be monitored from the Connexxion filling data. For the collection of experiences of drivers, passengers and inhabitants of Enschede living near the route (line 2) interviews and questionnaires were selected as tools. Also the maintenance and repair events would be logged by Connexxion for processing by the University of Twente.

The trainings of drivers and technicians were prepared in this phase.

In the final stage of building the buses some delay was caused by late delivery of some component and some system glitches requiring attention, but before the end of the year the vehicles were approved and roadworthy in Enschede, under scrutiny of Connexxion and adapted to 'practical use demands' before the driver trainings could start. The training had been prepared and the drivers were lined up to be trained in using the hybrids. As most of the interfaces were close to those on the commonly used diesel buses this did not require lengthy training. Some training time was used for transfer of the theory of the hybrid drive and the goals of the project. A first impression of the drivers' experiences was collected during the training. This was part of the execution of the monitoring plan of the University (finalized in March 2011).

The training of drivers and technicians took place in January and February of 2011.



Project Planning

Phase 2: Finetuning

As of March 1 2011 the buses were operated in regular service. By July they had covered (over the first six months of the year) the agreed annual minimum of 10000km. They performed well in general and did not manifest more problems or maintenance requirements than regular buses. As discussed more in detail in the next chapter the monitoring activities that were defined as elements of the project (not to be confused with the program monitoring activities performed by CE/Duijnn) were started. Technically the fuel consumption monitoring was the most important. As expected short term measurements showed severe fluctuations but averages were acceptably constant. A first round of interviews with the drivers was executed and the passengers were also interviewed in the first half of 2011. On the whole the experiences were positive (ref to chapter 4). Apart from the interview, feedback from the drivers during trainings and the first period of use was used for fine-tuning of the buses. Also the feedback from the Connexxion technical staff provided valuable feedback for VDL and Vossloh Kiepe. As a first impression it is worth noting that the buses were quite maintenance friendly. Where pilot vehicles often have maintenance accessibility issues, these hybrids did not. As the first results of fuel consumption measurements were disappointing more detailed monitoring of the energy use (e.g. for heating and air conditioning was discussed. It proved difficult to monitor additional data due to lack of specific equipment which was not foreseen in the design and development phase. It was tried to obtain load data related to the sections of the route. Weight measurements or e.g. weight counters measuring passenger weight upon entry and exit proved not to work. Deriving the number of passengers from OV-chipcard data was not feasible because it was not possible to easily get the required data from the system and because the percentage of passengers using the card was not a steady number at the time.

In the fine-tuning period a noise issue arose. In Helmerhoek people near the bus route complained about noise and vibrations. The Region and the municipality communicated very well on the subject and the University performed diagnostic measurements on one of the busses. Improvement on inlet and exhaust seemed necessary. VDL took measures involving the engineering and implementation of adaptations in the inlet and outlet system of the diesel engines. It took the buses out of operation for a while because the adaptations required preparation, and could only be implemented at the factory in Valkenswaard.

The complaints appeared to be partly specific for the hybrids but were also of a more general nature and were more based on the intensity of bus movements and the relatively short distances to the houses. Possibly the opportunity to react to the hybrid pilot buses was welcomed to raise the issue of bus noise in that area in general. However, by taking the complaints seriously and by acting on them and by informing the complaining inhabitants in sufficient detail in the end everybody accepted the solutions.

It was difficult to pinpoint the real cause of the noise issue. First of all there is the well-known difference between measured and perceived noise. (Where measuring is based on physical characteristics and perception also covers various psychological factors). Further it could well be that using a 4-cylinder engine instead of the usual 6- cylinder and operating that engine at several constant RPM’s is a cause of the differences. Measurements at the University of Twente showed that both the inlet and outlet systems of the diesel produced high noise levels. VDL redesigned several parts in these systems with the effect of lowering noise emissions. Communication with the complaining stakeholders, well performed by all under the coordination of the municipality helped in obtaining their satisfaction.

Phase 3: Testing and monitoring

Early in 2012 the noise issues were dealt with and in the first half of the year the control software of the drive system was upgraded. The main alterations were the activation of the GPS-link, the longer stretches of fully-electric operation and related to that the ‘deeper’ unloading of the supercaps. Also some other issues were dealt with such as the functioning of the power steering. Also the buses appear to be somewhat sluggish which puts pressure on the time schedules. No direct cause was found for this and as it did not cause persistent delays no further actions were taken. Another issue that was identified and solved was the high pitched sound caused by the electric pressure pump for the power steering. A sound insulating box, prepared by the Connexxion technical staff provided a good solution.

The issue of noise and vibrations was used as a focal point for public communication in this phase. A press release was prepared and an event was organized to present the busses with the new inlet and outlet system. Also the buses were present at the Mid Term Review event and at the hybrid users forum, both at the same day in Rotterdam.
An article was published in the regional newspaper Tubantia and the buses featured in a program on local TV. Also an article was published in E-mobility Magazine. Further www.lijn2gaatgroen.nl was refreshed.

Analyses of the fuel consumption showed that this was comparable with that of the other buses, the (lighter) Ambassadors. Some more insight was sought in modeling, comparison with SORT cycles and energy flow measurements with a data logging system on one of the vehicles.

In this phase the availability of the hybrids was determined: with some 96% they are a good match with the rest of the fleet.

As a side effect of the new software an issue arose with the starter batteries: these are differently loaded as the diesel is switched off on longer stretches. This caused several starting problems.

It appeared that in long, high speed curves the rear axles were noisy. The transmssion ratio of the differentials to match the electric motor are different from those used in the diesel version of the Citea. The noise, however, apparently originated from the differential gears. A clear cause was not identified and as there was no technical urgency and because the nature of the reportings (it did not occur frequently and the noise level was not very disturbing) did not make it a priority for modification of the pilot busses.

Fuel measurements were interrupted in a period when the data system of one of the busses was suddenly poorly calibrated. Some loss of data was the result, but this did not affect the results. Unexpectedly the software update did not lead to less fuel use. Possibly the efficiency gain in the diesel engine operation was compensated by an efficiency loss, due to the more intense us of the super capacitors.

In the second half of 2012 drivers interviews were performed and also the opinions of people living near route 2 were surveyed. The pilot testing was ended end of May 2013 and the buses were operated some time after that. The project was finalized in August of that year at an event in Enschede at which the experieces and expectations were exchanged. Final reporting of the project and the publication of the program monitoring results took place after that.

3.3 The budget

Although the execution of the total project took longer than expected all parties managed to perform their work within the overall projected budget and subsidy. Some extra service by Connexxion (spare diesel buses) were borne by Region Twente. If any other budget problems had to be solved these were handled by the individual participants.

It proved to be a good choice to put the remaining value of the buses to zero by the end of the project period. Not being standard there was no chance of selling them on the (international) market. After the project they were used during a short period by Syntus (the successor of Connexxion in operating the Twente concession). This was possible because the drivers and technicians followed the concession. In the end the hybrid were replaced by new Syntus equipment and returned to VDL. They will be offered for sale but as foreseen at the start of the project and also indicated by Connexxion there is little chance for success: Turning the vehicles into diesels is a substantial and costly process. From the perspective of the buyer operationally using the busses as hybrids is quite a challenge!

3.4 Future developments

When the program was started and when the project was defined the serial hybrid technology for this application was quite innovative. In the specific project the development that was foreseen qualified the project as an ‘alpha type’. This implies that at the time it was expected that if the prototypes would be a success, the next step would be to prepare a next generation ‘pre-production’ prototype for ‘beta’ testing.

The prototypes proved to perform quite well as reliable vehicles for public transportation. Also the ‘serviceability’ proved quite good. Therefore the development steps required to optimize those aspects could be limited. Production was done (as far as the innovative driveline was concerned) on a minimal series scale. For some components suboptimal solutions had to be used, because the small series did not provide the option (budget and time wise) to set special developments in motion. In terms of costs as well as in terms of energy use and space requirements optimization would be a part of this development step. In a next step an effort would be made on the optimization of components and production method. The key results in terms of fuel consumption and emissions was of a lower level than aimed for (refer to chapter 4). Before entering a next development phase it would be required to identify improvement options in this field to verify the viability of the business case.

Another essential aspect is the market for the buses. At the start of the project it was expected that the business case would benefit from the reduced fuel consumption and the increasing fuel prices. The reduction of emissions was considered to be very attractive for inner city use of the hybrids. Disappointing results in the fuel consumption reduction of the diesel hybrids and also the increased insight in the importance of reducing emissions in cities seem to have turned the attention for diesel hybrids into that for zero emission busses. The feasibility of the concept still requires attention. It translates in two fundamental questions concerning:

- Is the cost of operating the buses competitive?
- Is the emission advantage strong enough to develop a market demand?

On the basis of the results of this project a decisive answer to both questions is not possible (refer to chapter 4).

3.5 The project organization

In Chapter 2 the project organization was shown in two ways:

- The directly involved organizations and their relationships and
- The way the project organization was structured.

As to the first diagram it may be concluded that this remained a good representation of how the organizations interacted. It may be concluded that in practice cooperation was very constructive and both on an organizational and on a personal level commitment and contributions were excellent which undoubtedly has contributed to the overall success.

As to the second some observations are worth mentioning:

- The guidance committee was replaced from the start by a Project Advisory Group consisting of high ranking representatives of essentially Region Twente and the Municipality of Enschede and the management of VDL, Vossloh Kiepe and Connexxion as well as the head of department of the section of the University of Twente involved in the project. AgentschapNL participated as representative of the Dutch Government and Royal HaskoningDHV acted as secretary of this entity. The broad base of the consortium was thought to limit the effect of extra know how introduced through the guiding committee. Making sure the organizations were participating wholeheartedly and were aware of the project on a strategic level was considered a more effective added value. The focus shifted from supplying external feedback to providing support and decision making in case of essential issues. During the project it worked more in the opposite direction: this forum enabled the developments in the project to be shared with those responsible in the background.
- The PMG functioned well in optimizing the efficiency of the PEG by determining the priorities from progress meeting to progress meeting.
- AgentschapNL participated actively in the PEG. This was a valuable expansion of this group as it provided not only relevant know how and two way information transfer between the projects in the program but also insured that the project developed sufficiently in line with the goals of the programme. The PEG proved an excellent forum to combine all inputs and feedback from all participants. Both the general developments and the momentary issues were mainly managed from this group.
- The Project Communication Group functioned only in the early stages of the project and as a part of the PEG. The timing as well as the subjects for communication proved very tightly connected to the developments in the project. It proved ineffective to try and set up an 'independent' communication strategy and program. After a short period communication was made a part of the regular PEG agenda. Without explicitly laying it down in a strategy the participating organization had a sufficient understanding (and respect) for each other's communication wishes and opportunities to run a flexible program in which the activities were well coordinated. The buses and the site www.lijn2gaatgroen.nl were the main constant factors and press release were often used as an instrument to highlight events in the project. Specific actions worth mentioning are the special tickets for rides on line 2, to be obtained through the website and the way communication took place when the noise complaints were received.

3.6 Foreseen risks

As discussed in the previous chapter 'risk management' was a part of the project plan. Before the start of the project an inventory was made of potential risk factors jeopardizing the developments in the project. For each of these potential risks it was indicated how it would be mitigated if it would occur. Combining the chance of occurring (low or high) and the effect if it should occur (low or high) four categories were distinguished (QI low chance, low impact, QII low chance, high impact, QIII high chance, low impact and QIV high chance, high impact) as a basis for the management strategy to be applied. At the time of writing the proposal 13 specific risks were identified. Of course during the project some unforeseen risks manifested. These are marked with letters in each category.

Foreseen risks:

Product:

1. Start – stop system on the diesel engine is not functioning as expected. (QII)

   Developments:

   In the selection of the diesel engine a lot of effort was invested in obtaining the engine manufacturer's guarantee in spite of using a start stop system. In this manner the risk was minimized in a very early stage. No problems were encountered in this field.

2. In the design and development stage the flywheel might show not to be the desired, reliable energy storage system. (QII)

   Developments:

   In the early design stages lengthy communications took place with the British development group of the flywheel to be used. In the end the conclusion of the technology developers of Vossloh Kiepe and VDL was that the technology was possibly proven on a 'test bed level' but not yet ready for application in a pilot vehicle to be deployed under practical, every day conditions. On top of this the required volume for the flywheel unit caused concern, even more so as the reaction forces might demand important reinforcement of the bus structure, requiring additional engineering work and costs and adding weight to the vehicle which would have a negative effect on fuel consumption.

   When it was determined that a super capacitor arrangement alone could perform all energy storage requirements at an acceptable price and with limited risks the choice was made to abandon the flywheel based storage system for this alternative.

3. Insufficient performance of the control system. (QII)

   Developments:

   The expected complex and relatively new control of the whole flywheel system was eliminated with the choice for super capacitor storage. On the other hand the incorporation of the super capacitors and also other innovations such as the GPS link increased the development risk. As expected developing the control system (especially the software) in various steps avoided risks for the overall project.

4. Problems in integrating multiple components. (QII)

   Developments:

   Not only the energy management was innovative but also the coordination of all control systems on the subassemblies such as the diesel engine were challenging. The technological risks of complex integration were kept under control because of the experience of the technology developers, especially Vossloh Kiepe and the cooperation of all partners in the PEG. Development and implementation of the improved software did cause some project delay. On the other hand it worked well without problems once the buses were in service again.

5. Availability of the buses due to failure. (QII)

   Developments:

   The quality of the vehicles and the way service and repair was organized and managed by Connexxion, VDL and Vossloh Kiepe worked quite well. In the whole project period the buses were only out of service for days on two occasions:

   - for alterations, required to adequately deal with the engine noise problems and
   - for dealing with the power steering issues.

   Taking the buses out of service and bringing them back to the factory for analysis and modification caused some project delay.

6. Project targets not reached. (QII)

   Developments:

   Thorough preparations could not guarantee results to be achieved but it did assure the maximum effort for this. The result was that the vehicles proved reliable and functioned well. In the monitoring program, however, it became manifest that the fuel consumption (and therefore also the emission) targets were not reached. Unfortunately it did not become clear how this could be addressed in further tests. So this risk proved hard to manage during the testing period. The monitoring activities as a part of the project were quite limited and overall program monitoring did not develop well and in tune with the project. In an early stage it showed that fuel consumption was much higher than expected. Modelling and calculations (refer to chapter 4) were used to correct the result for the weight of the hybrid buses compared to the diesel Ambassadors. Analysis based on measurements of the energy use on board was impossible because there were no provisions made for these measurements in the original design and engineering phases. All in all three causes can be identified for this:

- monitoring within the system was not defined as something to be dealt with in the proposals (program demand);
- the overall program monitoring could have been effective if well defined before the program was launched and the project monitoring could have been well tuned;
- there was no budget opportunity to introduce improved monitoring in a later stage.

A. The vehicles disturb the people around the route with excessive noise

Developments:

This risk was not foreseen. As complaints were registered at the municipality the strategy implemented was to take them quite seriously and to demonstrate this through very open communication, a serious and scientific analysis of the issue and the development of an effective technical solution. Also a specialist analysis was performed on the damage that might have been caused to houses. The municipality took care of communication and provided for the damage analysis, VDL and the University took care of the analysis after which the buses were taken back to the factory. Modified inlet and outlet components were designed and manufactured after which the buses returned to service.

B. An unexpected characteristic of a major driveline component puts the vehicle functionality in jeopardy.

Developments:

- In accelerating from standstill the buses were unpractically - and in some cases dangerously - sluggish. At first it was thought that this was a combination of the higher weight of the buses and the energy saving way the ‘drive-by-wire’ system was tuned. It was improved sufficiently but it was also determined that a fundamental aspect was in the time required to bring the electromagnets in the main electric motor into saturation. Possibly a change in driving is the inevitable solution. This may prove difficult in mixed fleets!
- In the design a pump for the power steering was driven by the diesel engine when running and another one by an electric motor when the diesel was shut off. Feeding the system at all times was of course essential and this solution was expected to be the most energy efficient. However, the drivers could feel the difference between both pumps when driving. On straight stretches this was awkward but did not have important effects. When turning, however, the changing power factor could be surprising and even dangerous. It did cause unexpected moves, noticed by the passengers sometimes. Adjustments improved the issue but it was not possible to totally remove the effect.

C. Leaving the bus stop inevitably gives the whole bus a jerk.

Developments:

This issue came up very late in the project. The manufacturer expects that it can be solved with brake adjustment.

D. Roll back on slopes.

Developments:

During stand still on an up-slope the vehicles tend to roll backward. This results in tricky situations when the next vehicle in line stops at a short distance. This issue was accepted by the drivers and has not caused accidents, but it would require attention in a next generation.

Price

7. Investments unexpectedly high. (QII)
   Developments:
   In the project all parties performed without unsurmountable budget problems.

Place

8. Number of stops exceeds capacity of start-stop system. Q(II)
   Developments:
   The engine supplier accepted the start – stop system for this project. No problems were caused during the tests. It looks, however, whether unlimited start – stop use will not easily be accepted by the engine manufacturers.

E. Poor acceleration leads to unpleasant or unsafe conduct in traffic
   Developments:
   The poor acceleration was an issue for the drivers. Merging into a dense traffic stream was too slow compared to diesel buses. The issue was mainly a late response of the vehicle to the accelerate command. By adjusting the 'drive by wire' system the effect could be mitigated, but it should be an issue to be solved in a next generation

Promotion

9. Negative press coverage even before project start. (QII)
   Developments:
   Communication was seriously set-up in the project plan. It was decided not to develop a fixed strategu an plan, but to take action according to project needs. Communication was a fixed issue on the agenda of the PEG meetings and activities were started when opportunities arose. As a result the press did not report negatively on the project, opposition did not develop and awareness of the project was widely spread. The websites of the Region and the Municipality were well used in communication about the project.

F. Publicly expressed complaints about the vehicles during the project.
   Developments:
   People living near the southern part of route 2 complained about noise and vibrations. By taking the complaints seriously and working on analysis and solutions the complainers respected the parties in the project and were cooperative in accepting the solutions.

People

10. Expectations too high or changing. Q(IV)
    Developments:
    The directly involved stakeholders have not run into this risk. Partly this may be because the vehicles looked good and performed well and for another part the information communicated about the project apparently gave rise to well-balanced expectations.
11. Negative attitude of primary stakeholders (drivers) in case of disappointing test results. Q(IV)
    Developments:
    Although the buses proved to be quite reliable and were initially well received by the drivers not all of them were enthusiastic until the end. Lessons learned from this are that it is:
    - it is not desirable to introduce one or a small number of busses into a large, homogeneous fleet and rotating all drivers for shift on the exceptions. Drivers do not get the chance to get fully acquainted with the bus (or buses) experience it (or them) as exceptional. In the end the differences will turn out to be disadvantages;

- it should not be underestimated that the bus is the drivers work station. Even small annoyances become big ones if you are confronted with them during a full shift!
- it may be effective to give the drivers a more active role in a pilot project. Demonstrating that their feedback plays a role will improve their acceptance of the machines.

As a conclusion: the risk was well identified and the management strategy well defined. However, under the circumstances in the project the result was not optimal.

12. Poor decision making in the project team causing project standstill. Q(II)

    Developments:

    In the project management structure it soon turned out that the PEG performed the key role. The PMG was useful as it set the priorities for the PEG. The PAG was available for control of escalated problems, but these did not show. The option to incorporate a novel rear axle was escalated to the PAG eventually but a decision was taken and accepted and the project was continued.

13. Planning control unsuccessful. Q(IV)

    Developments:

    The preparation of the key contract (between Region Twente and the technology developers VDL and Vossloh Kiepe took quite some time and effort. Planning delays did occur but did not jeopardize the work in the project.

    In the end the positive conclusion is that all parties involved were committed and quality was not sacrificed for time.

3.7 Process conclusions

In the beginning of this chapter there were 6 main questions to be answered concerning the way the project was executed and how it developed. These are discussed in this paragraph.

1. *Did the group of organizations executing the project cover all relevant fields in order to make the project successful?*

The aim was to develop and test serial hybrid (diesel – electric) buses for inner city public transportation. So in the core there had to be a technological group capable and willing to take up the development and the testing of innovative buses with the aim of reducing fuel consumption and emissions. For this testing it was required to also incorporate a bus operator. The bus operators are the market for the product to be developed, so having such a party in the team was not only a requirement for testing under practical conditions but also an asset in the design and development representing the users of the buses. Of course a transport responsible authority and a (geographical) host were essential for the testing in practice. Important capabilities could well be deployed o broaden en optimize the monitoring efforts in the project (in all stages but of course specifically in the testing phase): a suitable research institute would add value to the group. For the management of such a broad project with such a differentiated group of participating organization a managing consultancy firm completed the picture.

To this executing group the input by the Dutch Government as sponsor through a specific subsidy program was added. In the end the group of organizations filling these positions in the project covered public authorities and private organizations and was even international as Vossloh Kiepe from Germany was one of the key technology developers/providers. The roles were quite different as were the profiles.

- The national Government wished to stimulate innovation in public transportation buses and provided substantial financial support to pilot projects by setting up a support program in this field.

- Agentschap NL (presently incorporated in Rijkswaterstaat, the government Department of Waterways and Public Works) provided the programme management, monitored and exchanged the developments in the projects on behalf of the Ministry.
- The Municipality of Enschede aimed at quiet, clean and energy efficient public transportation in Roombeek.
- Region Twente was motivated to facilitate the innovation and the pilot as a part of the Twente public transportation contract. The subsidy was channeled by the Ministry through the regions budget so effectively Region Twente had the central role in the project.
- Public Transportation Company Connexxion participated as the operator of the buses and provided both the functional specifications as the operation including drivers, maintenance and repair etc.
- Bus producing company VDL and electric drive and control specialist Vossloh Kiepe developed, built and tested the two serial hybrid buses.
- The University of Twente participated with the task of the project monitoring.
- Royal HaskoningDHV supporting Region Twente as managing consultant.

With other organizations all participants (except the Ministry and AgentschapNL) had already teamed up in a consortium for development and testing of serial hybrid buses on a European scale. An advantage of this definitely was that parties were aware of the complexity and the risks of the project. The project proposal had a sound basis and was well conceived as demonstrated in the execution (as discussed in this chapter).
Arranging the responsibilities and risks in the ‘underlying’ contacts once the project was awarded government support was a lengthy process. The contract between Region Twente and both main technology providers were difficult because technology development is not an everyday issue for the Region on the one hand while both technology providers felt sufficiently stretched for their own part ad were not eager to bear additional risks in accepting the responsibility for the whole product or project. After a lengthy process, managed by Royal HaskoningDHV one contract connecting all three parties and committing them collectively was signed and the project could start. It may be considered proof of the quality of the discussions in this stage that none of the issues played a role in the project.

It may be concluded that the combination proved well defined for the job. It is important to note that the group demonstrated to also be capable of effectively deal with the less explicitly predicted issues that were encountered.

2. Was the project organization adequate and effective?

As described in Paragraph 3.5 the organizational set up of the project has worked well. Some of the foreseen elements in the project organization developed different from the set-up in the proposal, but the originally designed project organization formed a good basis and a good starting point. Apparently the knowledge and experience base of all participants and the open (sharing) attitude proved the original idea of having a ‘Guidance Committee’ superfluous. This was changed into a ‘Project Advisory Group’. In this group the managers and governors responsible for the project in the participating organizations were given a position to provide overall control and to ensure that the Project Management Group and the Project Execution Group stayed on course and would not get stuck in a ‘lock up’ situation. It may be concluded that the way the PEG functioned the foreseen roles of the PAG were not used and its existence was mainly valuable as it provided the project and the cooperation to be well anchored in the participating organizations.

In a very early stage the frequency of PEG meetings (prepared by the PMG) was set at once every month; This proved to be a near optimal choice: it matched the speed of developments well and although it was an effort for the participants the efforts and the effectiveness were well in balance. In the testing phase the speed of developments decreased so it was decided to lower this frequency to once every 2 months. As the delay in the project execution would have increased the number of meetings the lower frequency was also welcome from a budgetary perspective. On the downside it was found that acting upon developments was slowed down and this was only partly compensated by more intermediate communication e.g. by telephone or e-mail. Also the 'peripheral' exchange of information about the project, the organizations and the 'events in the public transportation bus world' dropped to a lower level.

It may be concluded that the project organization was sufficiently flexible to be adapted to the needs and provided a good basis for good project execution. It should be stressed that the way organizations and their representatives cooperated was decisive for the effectiveness of the project organization.

3. Could the planning be followed?

In the original proposal the project was expected to start in August 2008 and to be completed in May 2012. Reality has shown that the start was delayed to March 2009 and completion was delayed to May 2014. The late start had two main causes:

- delay in final budget commitment from the program and
- time required to set up the central contract between Region Twente, VDL and Vossloh Kiepe.

Although it was tried to limit the starting delay by starting critical activities even before the final budget allocation from the program was confirmed (e.g. specification and procurement of major components), it was considered essential to develop a contract the could be wholeheartedly signed by the key players. As this involved dealing with substantial risks for public and private organizations of which one located in Germany it took its time. In order to have a realistic planning at the true start of the project the original schedule was shifted to a start in March 2009.
The activities in the preparation phase were as planned very much executed in parallel. This was even intensified by the nature of the development project and the e.g. dependence on suppliers. In the end of this phase the inevitable time loss had accumulated to 6 months and one more month was lost in the period in which the vehicles were fine-tuned in practice and in which drivers and technicians were trained. The testing under practical conditions started in September 2009. In this period some time was lost in the noise problems and the introduction of new control software and the testing period was concluded in May 2013.
A closing event was organized in August of that year. Finalizing the evaluation and reporting took until May 2014.

It may be concluded that the planning was thoroughly prepared and used for management of and communication within the project. In executing the project the planning helped to balance time and results. Due to several factors – both of a technical and of an organizational nature – the overall project time was longer than foreseen at the start.

4. were there any specific financial issues?

Undoubtedly the longer project period increased the costs. The budget limitations also limited the options for optimal response to technological developments in the market (e.g. the ZF axle which became available). Also this excluded the option to add monitoring equipment to improve understanding of the energy balance of the buses. On the whole the project was fully executed as planned and any budget issues were dealt with by the project group.

It may be concluded that the initial agreement on financial risks to be primarily borne by the participating organizations worked out.

5. Did the risks that were previewed and their management prove useful for project success?

As discussed in detail in paragraph 3.6 it may be concluded that introducing risk management in the proposal stage and executing it in the project period has worked well. Fortunately not all foreseen risks manifested. Those that did were well coped with. As to be expected also unforeseen risks could have endangered the project. Those that were identified as such (refer to paragraph 3.6) were managed as those that were foreseen. None of the risks proved fatal for project completion.

It may be concluded that risk management was well prepared in the proposal phase and probably contributed much to the success of the project..

6. Were the consecutive stages in the process effective and efficient?

In preparing the project, the main phasing was clear in an early stage:

0. preparation of the project plan;
1. preparation phase: development and building of the vehicles and preparations for testing;
2. fine-tuning of the vehicles and the drive system; first monitoring activities;
3. testing and monitoring
4.

and as continuing activities:

5. communication
6. project management

Detailing these was valuable for understanding what each participating organization would have to do for a successful project and to develop a basis for project planning.

In the execution of the project the detailing of the activities proves useful for project coordination and communication. It also showed that especially in the development phase planning was much more dynamic than the schedule: activities ran much more in parallel en interaction with external parties (e.g. suppliers and licensing authorities) manifested as inevitable and forced adaptation of the planning to stick as much as possible to deadlines.

In the fine-tuning phase preparing the vehicles for real operation in the testing phase was the dominant goal. It was not an option to save time by starting the testing phase before finalizing fine-tuning. It also was a phase in which working was done in Enschede and not at the factories of the developers. This implied, of course, extra scheduling and time challenges.

As always in a development oriented project the planning was a very important tool for management en communication. In those types of projects it is also very difficult to control the planning. Unforeseen events are in the nature of the projects: the completion moment has to be balanced with the final result. Compromise is inevitable.

It may be concluded that project phasing was well devised. It was effective in project preparation, formed a basis for the planning and provided a good basis for management of and communication in the project.

4 RESULTS

In the previous chapter the execution of the project (the process) was analysed. In this chapter the results of the project are looked into and it is discussed how these match the targets or not and why. On the basis of this analysis and taking external developments into account the last four of the evaluation questions listed in the beginning of chapter 3 will be presented.

4.1 Program and project monitoring

In the program ‘Pilotprojecten openbaar vervoer per bus’ it was foreseen to have an overall monitoring program assuring that the results of the projects within the program would provide a basis for comparison in order to derive overall results as a basis for further development. The Ministry announced to appoint an independent party for coordination, streamlining and guidance of the monitoring activities in each pilot project as well as for additional research if required in order to assure that the abovementioned goal of the program could be reached.

In the program announcement it was indicated that obtaining sound and publicly available operational information on the use and the environmental effects of innovative buses was the goal of the program. This information should then enable transport authorities and transportation companies to improve the sustainability of public transport services. For this reason monitoring should be a part of each project.

In this project the serial diesel electric hybrid propulsion implied a substantial change in the structure of the powertrain (no gearbox and clutch, a four cylinder diesel engine, a generator, an electric motor and an electric backbone with supercaps for storage of electric energy) largely in the same space as the standard powertrain (apart from usage of the rooftop) with complete new power management. With this in mind

- feasibility – is it possible to develop this new power train in an existing vehicle –,
- reliability – how are the vehicles performing in daily service -,
- maintenance –how are the vehicles from maintenance perspective –,
- fuel consumption – is the efficiency target met –,
- drivability – from the perspective of the driver –,
- comfort – from the perspective of the passenger –,
- influence on surroundings – perspective of the neighborhood - and
- business case – from the perspective of Connexxion -,

were relevant items for evaluation. For these items it was tried to find answers in the project’s monitoring program. An independent party would be appointed by the Ministry for streamlining and guiding the monitoring activities of each pilot project as well as to coordinate additional research (like SORT-tests), in order to assure that the abovementioned goal of the program could be reached. In the project monitoring of emissions such as $CO_{(2)}$, NOx and particles were foreseen to be part of a laboratory benchmarking as a part of the overall monitoring by this independent party.

In the project proposal the monitoring activities as a part of the project would focus on the technological aspects of fuel consumption and maintenance and repair event as well as on surveying user experiences. In the latter part three specific user groups were distinguished:

- inhabitants of Enschede living near the hybrids’ route,
- passengers on this route and
- drivers operating the hybrids

During monitoring some things came as a surprise:

- Measuring fuel consumption and distance travelled proved to be less reliable than expected. At the end of a day of service the vehicles were refueled, but there is no clear defined level in the fuel tank where the nozzle would stop filling. As a result the fuel consumption results per day fluctuate. Also the data exchange between vehicle and nozzle was not always reliable. During part of the monitoring period the calculation of the distance travelled (based on the revolving wheel) went wrong due to an incorrect setting.
- In order to select per day those busses in the Twents fleet which ran only on a city-service extra information by Connexxion was required. This information was hard to come by and came available very late in the project.
- Group dynamic processes within the driver population changed the attitude towards the hybrid busses from positive to negative. This dynamic was encouraged by the incidental use of these two hybrids by a driver. The driver had to get familiar with the specific look and feel each time again. This was the consequence of the choice made by Connexxion at the start of the project not to change the driver-vehicle planning and thus to treat these vehicles as any other vehicle in the fleet. Assigning a small group of drivers specifically to these two vehicles could have overcome this problem, but this would have changed the driver-vehicle planning.
- The early morning start procedures gave conflicts with the motor management of the hybrids. Before the drivers arrive the engines are started. The motor management was not robust for long-time idling. This resulted in full depletion of the starter battery and thus to failure and extra wear of the battery. Note that guidelines for energy conservation and engine preservation advise to avoid any idling.

As a choice the pilot buses were to be part of the regular fleet of buses as much as possible. Also in the design (possibilities for monitoring) the focus was very much on ‘business as usual’. From both perspectives some more attention (and money) for monitoring could have given more and more reliable results. In retrospect this could largely have been covered without violating the desire for ‘normal operation’.

In the project plan it was indicated that for this alpha project the results should be a good basis for the next development step of the technology. From the monitoring results it should become clear that the technology in the buses should (potentially) achieve:

- 50% reduction of the CO_2 emission of that of a similar diesel bus (‘tank-to-wheel’)
- 25% reduction of other emissions compared to an EEV bus,

And it should also demonstrate that the prototypes are a good basis for buses to be made in series and identify which feasible adaptations are required for that.

4.2 Fuel consumption

In May 2009 the formats for the program monitoring were discussed. The monitoring program that was a part of the project was presented in more detail by the University of Twente. The most important goal to be achieved with these vehicles was to substantially reduce fuel consumption and CO_2 emissions (by 50%) and also the emissions to air of CO, HC, NO_x, particles and smoke (by 25%).

As a routine all Connexxion buses in the TWENTS fleet were filled up every day after service. At this point the quantity tanked, the kilometers driven and the bus identification were registered. Applying special fuel measuring equipment on board was considered expensive, vulnerable and was not expected to give relevant additional information. It was therefore decided to use the daily registrations as a basis for fuel consumption determination.

For reasons explained in the previous chapter the hybrid buses were developed on the basis of a VDL Citea. In the Enschede fleet Connexxion used mainly VDL Ambassador diesels. Also on line 2 the regular service was provided with Ambassadors. A perfect reference vehicle was therefore not available and accurate determination of the difference in fuel consumption would only by possible with adaptive calculations[1]. From experience of both VDL and Connexxion the weight would be the main factor requiring correction. As a rule of thumb a starting point was that every 1000kg of extra weight would increase fuel consumption by 7%. The Citea is some 1500 kg heavier than an Ambassador at an indicative weight of 10 – 11000 kg. Rebuilding of the Citea to a hybrid adds another 2500 kg, so the weight of the hybrid exceeds that of a conventional Ambassador with 4000kg! It was hoped that the roller bank test, a part of the overall monitoring would provide relevant input but these never substantiated.

In the elaboration of the modelling the fuel consumption was assumed to depend on:

1. ***The basic vehicle weight,*** a known factor
2. ***Number of passengers***
   The number of passengers determines the variation of the total weight from stop to stop and therefore influences fuel consumption. It was expected that this parameter could be derived sufficiently accurately from OV-chip data. However, during the testing period the OV chip system was still being implemented and used in combination with the traditional ticket system. So even if it had been possible to obtain the data these would not have provided reliable stop – to –stop information on the number of passengers on board.
   It was investigated whether a reliable and affordable counting system could be used, but experience of Connexxion indicated that counting should then be done near the doors. Especially upon entering passenger behavior had proven to be too erratic for accurate measurements.
3. ***Number of stops***
   At each bus stop the vehicle has to accelerate from stand still. This requires energy and therefore is partly causing fuel consumption. At the next stop the vehicle will slow down and stop. The energy used for accelerating is recovered for an important part by the brake energy recuperation system.
4. ***Driver behavior***
   Research at the transport companies has shown that driver behavior substantially influences fuel consumption. It should be noted, however, that dense traffic sometimes limits the drivers' options.
5. ***Auxiliary energy demands***
   A public transport bus primarily requires energy for driving. The energy requirements for supporting purposes such as heating and cooling can be substantial. No sensors or equipment were foreseen to monitor these power consumers
6. ***The specific route***
   Many characteristics of the specific route at which the bus is operated determine the fuel consumption. The length, constraints, stops other than bus stops such as traffic lights will influence the actual diesel use. The time schedule is a factor of influence very much related to the route.

All in all the only measurements that could be done were the daily filling measurements by Connexxion. Even these require alertness as demonstrated when the data showed inexplicable deviations, later proven to be caused by the system installed on the busses and the 'filler guns'. Fortunately the faulty data were identified and could be removed, leaving enough reliable data for a basic analysis. Quantifying the other parameters proved impossible with any accuracy. Only modelling with data from literature provided a basis for the overall energy balance.

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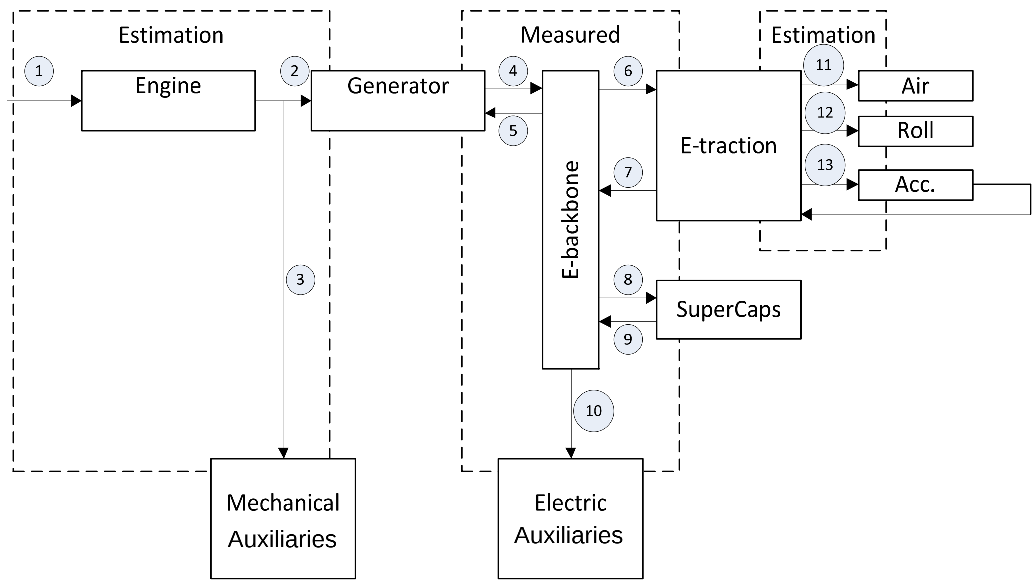
[1] At this point it was expected that roller bank tests provided as a part of program monitoring would provide additional comparative information.

An analysis was made over the last four months of the testing period of the fuel use of the hybrids on city line 2, all Twents busses (Ambassadors) on city lines and all Twents buses on non-city lines. The averages were 0,355, 0,353 and 0,308 l/km respectively. It may be concluded that the hybrid Citea's had an almost identical fuel consumption as the diesel Ambassadors on the city lines. Using the rule of thumb that every 1000 kg of additional weight increases the fuel consumption by 7%, the energy saving was more than 25%. On the pessimistic side the weight difference was caused by two reasons:

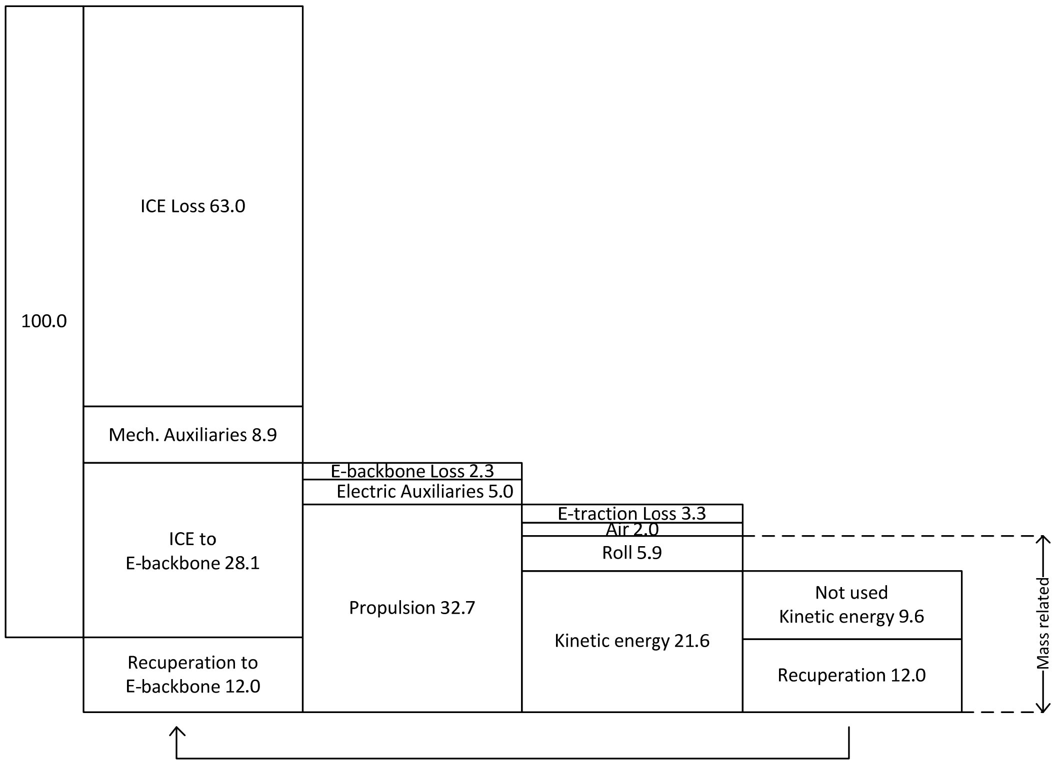
- A bus capable of carrying the extra loads caused by the hybrid driveline had to be used as a starting point.,
- The components required to transfer the bus into a hybrid added some 2500 kg to the weight!

As a conclusion on the fuel consumption it may have been demonstrated in this pilot project that even a first generation hybrid driveline on a city bus can save roughly 25% compared to a diesel doing the same work. In this stage of development, however, all of the fuel saving is lost on the weight increase inevitable for the transformation. Some optimization on the driveline and the auxiliaries not driven by the engine and some weight optimization as a next step will undoubtedly improve the comparison. However, it seems unlikely that 25% fuel saving can be achieved let alone 50%, which was one of the goals of this pilot project

For a better understanding of the fuel consumption, the energy flows in the bus were pictured as sketched below, where number 1 indicates the energy input or the fuel supplied.



Based upon literature an approximation of the energy balance was constructed giving more insight in where the energy goes in a city bus for public transportation. Note that only the primary loss in the diesel engine is indicated as a loss. E.g. involuntary heat production in some auxiliaries of course may be considered as a secondary loss of energy. Note also that the numbers are approximations derived from various literature sources.



This analysis clearly shows that more than 60% of the energy fed into the vehicle is lost before the electric energy required for nearly all functions is generated. The auxiliaries, excluding heating, consume almost 14%, the rest is used for propulsion. More than half of this latter portion is recaptured instead of lost by braking (and turning into heat). Note that busses on line 2 stop regularly (apart from stops due to traffic situations there is a bus stop at every 420 meter) and have al low cruising speed (maximum 50 km/h and even 30 km/h on the northern part of the line). As result of this almost all propulsion energy is needed for mass related resistance (rolling- and acceleration resistance).

4.3 Other emissions

The other emissions targeted were not monitored separately in the project. Although the diesel engine, the sole source of the emissions was used more on constant speed it would be jumping to conclusions to state that the other emissions decreased. For one all development efforts were focused on fuel consumption and also in the end the same work was done by a smaller engine.

Further it should be noted that the traditional auxiliaries are major energy consumers on public transportation buses, although no exact figures were found during the project. The impression is that energy – and thus fuel – can be saved by improvements in this field. However, these options will not only work for hybrids: they will also improve the fuel bill of a straightforward diesel.

No conclusions concerning the ‘other emissions’ can be drawn from the project. No measurements were done and there is no basis for correlation between the fuel consumption and these emissions.

4.4 Maintenance and repairs

Maintenance and repairs had been identified as a priority issue in the project proposal. The Connexxion technical staff working on the Twents fleet had a long working relationship with VDL already. They were instructed by VDL and Vossloh Kiepe on the specifics of the hybrids and both technology providers had arranged excellent back up support. Sometimes the busses had already ‘remotely’ reported an issue to VK before the Connexxion staff did. The workshop maintained a log of all incidents which was analyzed by the University. By far the majority of the efforts was the same as for the diesel buses. None were disabling problems which under regular conditions would take the vehicles out of operation for an extended period.

Of the issues specific for these prototypes three categories can be mentioned:

1. issues stemming from the design
2. issues stemming from the assembly
3. issues from specific components

Examples:

1. issues stemming from the design
   - The busses reacted (too) slow on the accelerator. Actually this was a compound issue that partly originated from the drive – by – wire system, intended to improve fuel consumption by preventing the driver to unnecessarily accelerating and partly from the time that the main drive motor needed to build up a magnetic field when being activated. The first aspect could be adjusted, the second was fundamentally linked to the motor selected.
2. issues stemming from the assembly
   - On one of the buses one of the cooling fans on the roof was noisy. A faulty connection caused the fan to run in the wrong direction. Once identified and corrected the issue was solved.
3. issues from specific components
   - The selected diesel engine (4-cylinder 178 kW Cummins) was smaller than the type usually applied on the Citea models (such as 6-cylinder 228 kW DAF). This and the use on specific RPM’s was the cause of the unusual noise characteristics of the busses (ref to ch. 4.8).
   - The hydraulic power steering is provided with hydraulic pressure from a pump directly driven from the diesel engine on a standard bus. In this case – as the diesel is shut down part of the time – also an electric pump was applied. This proved noisy, which was more noticeable when the engine (an accepted source of noise) was shut down. In addition the drivers reported that the two pumps caused a noticeable difference in the steering force required.
   - At higher speeds the differentials became noisy in curves in the road. The axles and specifically the differentials deviated from the ones normally used in the Citea due to the different input RPM (directly from the electric motor instead of from the diesel through the gearbox). Apparently the differential gears caused the noise. Possibly finetuning the gears would have reduced the noise levels. The nuisance, however, did not require further action during the testing period.

From the maintenance and repairs analysis it show that the pilot busses performed quite well, that the experimental driveline gave no direct problems and that the cooperation between the technology providers and the operators’ technical staff the pilot hybrids’ performed as regular diesels in service.

4.5 Inhabitants survey

Part of the monitoring program in the project aimed at inventory of the experiences of inhabitants of Enschede living near the route of the hybrids. A flyer was developed by the University of Twente for this. The flyer served the combined purpose of informing the inhabitants and providing them with a questionnaire for this ‘inhabitants’ survey.

Route 2, which was the route selected for the pilot project, services in the North Roombeek and Deppenbroek and in the South Helmerhoek. Typical for this route is the high percentage of specific bus lanes. They are close to the houses and interact intensively with the gardens and recreational areas. It may be expected that the inhabitants of Enschede near this route are very well aware of the busses.

In preparation of the questionnaire the potentially relevant issues from the perspective of the inhabitants were inventoried as:

- Noise
- Vibrations
- Specific diesel engine start – stop behavior
- ‘Lack of logic’ relation between speed and sound
- Lack of audible gear change
- Smell
- Safety in and interaction with traffic
- Accessibility for handicapped

It should be noted that it was thought relevant for obtaining a suitable response that the number of questions should be limited. The questions were formulated and selected in such a way that a thorough statistical analysis was possible in order to determine the significance of the results.

In the results it showed that of 1800 questionnaires distributed almost 10% was filled out and returned with a higher percentage from the southern loop than from the Northern loop. It should be noted that the northern area is less densely populated: the Southern loop population density is much higher and more people live close to the bus lane.

Half of the responding households consists of two persons, 22% of one person only. 20% of the families have children. More than 75% of those that responded have traveled on one of the hybrids.

Overall the inhabitants have a fairly neutral position on the hybrids although there is a significant difference between the people near the northern loop and those near to the southern loop. The later feel substantially less happy about them especially on noise and vibrations and the start – stop system.

Those living near the bus lanes (<5m) feel significantly more negative about noise and vibrations than those at greater distances (>50m). Some not only blame the vehicle but also the driver and his driving style. Some remarks were made warning that too quiet may be a risk e.g. for the handicapped and for playing children.

As travelers the respondents were the most critical about the interior of the buses (also found from the passenger’s survey ch. 4.6).

As seen from the travelers survey also from the answers of the inhabitants it can be learnt that not so much the driveline technology is considered relevant, but more so the interface of the bus with its (human) environment. In this aspect both the vehicle and the driver are under scrutiny.

From the inhabitants survey it shows that people are not insensitive for the sustainability aspects of public transportation. As inhabitants their priority is the safety and the nuisance caused by the vehicles. The essential parameters from their perspective are both the vehicles and the way these are driven.

4.6 Passengers survey

On March 29 2011 (a warm and dry, cloudless day) 149 people were interviewed in two hybrid buses and in a random selected Ambassador bus to analyze the experiences of bus users with the new hybrid buses. Approximately 75% of the interviews took place on the hybrids, the rest on the Ambassador. People using the bus were interviewed at random. Only a few refused to cooperate.

The interviews were well prepared and executed with a detailed questionnaire, filled out on the spot by the interviewer. In the forms it was indicated on which bus the interview took place, whether a man or a women was interviewed and if the interviewed person was aware of the pilot with hybrids. If so it was further checked how one had been informed and if one was aware of the specific type tested. All interviewed passengers were asked 8 specific questions about the vehicle after which it was checked how frequently bus line 2 was used and for which purpose.

65% of the people interviewed were female, the others were male. Almost all people interviewed knew of the pilot with hybrid busses (slightly more than 80% on the Ambassador, well over 90% on the hybrids). Most of the interviewed passengers were regulars on line two (more than 75% used line 2 at least twice per week. Almost 70% used this bus line to go to work or school or to go shopping.

Of the hybrid passengers many – more than on the Ambassador- know that the bus is either hybrid or electric and that it is environmentally friendly. Almost half of the hybrid passengers think it is less noisy (only a bit more than 20% of the Ambassador travelers shares tis opinion.).

The comfort of the hybrids is criticized. This seems to be mainly the difference between the Ambassador (Originally a design for inter-city transport and the Citea, originally designed for inner city transport. The differences are e.g less and less comfortable seats and relatively more reversed seats.

It seems that the passengers have little to say about the pilot busses being hybrids: they look at them as busses, means of transportation and liking or disliking them seems to point more at the basic difference between Ambassador and Citea than that between hybrid and conventional driveline.

The passengers are interested in the sustainable innovations in the busses. Most important to them, however, appears to be the comfort.
Most of the passengers are regular users choosing public transportation to go to work, school or shops.

4.7 Drivers survey

First Impressions

In January 2011 the prototypes were ready to roll and approved by the RDW, so the training of the drivers could take place. Some information was prepared for them presenting an overview of the project goals, the targets aimed at and the technology of the busses. Some attention was also given to the reporting of observations and experiences to the workshop. The training itself was part theoretical and the other part a ride on the Northern half of route 2. On this occasion three randomly selected drivers were briefly interviewed before as well as after their test drive. During that ride they were observed. Of course this does not give a statistically representative result, but it does give a rough impression of the start. Before it was decided to focus at least on the aspects: acceleration and braking, road behavior, steering, and suspension and noise.

Before driving the drivers were interested (or even curious); positive on some issues, skeptical on others. After driving all drivers were content with road behavior and suspension. Acceleration was considered slow but acceptable. Slight ‘roll-back’ when starting uphill was noticed, but not considered problematic. Steering was noticeably different from the Ambassador, but not an important issue. One of the drivers noticed a difference in power steering between diesel running and diesel switched off. Noise was not judged as much different from usual and the missing relation between engine RPM and vehicle speed was not seen as disturbing. Braking was judged different by the drivers: one had a problem in ‘shock free’ braking the others noticed different behavior but could well cope with this.

When first introduced to the hybrid pilot buses the (small number of) interviewed drivers were interested and positive. The drawbacks they saw did not seem to spoil their work experience

In depth survey

Near the end of the testing period (June 2013) a thorough survey of the drivers’ opinions was performed by the University. In the team a student participated who worked part time as a Connexxion bus driver in Enschede. He was particularly suited for the communication with the drivers and the interpretation of their answers.

The drivers were interviewed while driving a hybrid in normal operation. A strict condition of course was that the driving and the safety had total priority. A questionnaire was used for reference, but the drivers were given ample opportunity to discuss any aspect they considered relevant. 14 interviews were held in a two week period.

The drivers interviewed:

- 11 men and 1 woman;
- 11 full time employees and one part timer;
- ages ranging from 35 to 61 years (average 51,5);
- working experience from 7 to 36 years, (average 22,5);
- 9 drivers have been trained for energy efficient driving (between 2010 and 2012).

So in general the drivers interviewed were male, not too young and had quite a track record as bus drivers.

It was recorded that the drivers as a group manifested a negative attitude towards the hybrids. In the interviews the opinions were much more individual and articulated. It should also be noted that many

opinions on the hybrids were using the diesel Ambassadors as a reference. Adjusting when changing busses was reported as unpleasant. It was seen as a disadvantage that the hybrids started as identical twins, but grew increasingly different during the testing period.
From all interviews the general ‘negatives’ were:

1. slow reaction to the accelerator pedal,
2. low power and torque,
3. difficult dosing of brake power,
4. poor sensitivity of the brakes,
5. shock when released from halting’, the drivers have no control and if passengers are still upright they may fall. Also the halting brake could not be released before the doors were completely closed even if all passengers were already seated.
6. roll back when starting uphill. (The diesel busses with automatic gearboxes ‘releasing the brakes’ also releases the clutch, giving the bus a forward thrust. In the hybrids releasing the brake, just releases the brake. In combination with the delay in the electric motor picking up, this causes the roll back.
7. use of one buzzer for both the indicators and the halting brake.

The relevance of these negative aspects differed a lot from driver to driver: some were overall positive, others practically refused to use these vehicles.

Four groups of characteristics appear to determine drivers’ acceptance:

- throttle related (the hybrids use drive-by-wire principles, the drivers are used to direct control systems). Also all drivers interviewed report a slow response and also (too) slow acceleration. In the interviews different throttle response between diesel running and diesel not running were mentioned. The observation was that acceleration was stronger when the diesel engine was running. Some report the impression that power diminishes when the stored energy in the supercaps runs low. Some feel that the feedback from the accelerator pedal is not always consistent. Some drivers notice that when the accelerator is released, the hybrids slow down quicker than the conventional diesels.
- diesel start-stop control. The drivers do not appreciate not having control over when the diesel engine is used;
- steering control. The different characteristics of the power steering between diesel engine running and diesel engine not running is disliked; at the start of the tests there was a delay before the electrically driven system picked up. After readjustment this problem was solved.
- braking. In the hybrids – inevitable when brake energy is recuperated – the braking is fully ‘by wire’. The braking action is related to the brake pedal position not to the braking force imposed by the driver; For the drivers this is an unpleasant sensation: it is workable, but unpleasant.

Further aspects mentioned as negative from driver perspective were:

- behavior in curves, (the hybrids feel a bit top-heavy),
- low power and torque,
- climate control,
- user friendliness,
- hard ‘to get a feel for’,
- on board equipment
- breakdown sensitivity (perceived, not so much experienced)
- service support

On the positive side the interviewed drivers mention the behavior on straight stretches as very comfortable and also the availability of a radio is appreciated.

Mixed reactions are given on the passenger space of the hybrids. Some say it is noisy and passengers report that the seats are not very comfortable. On the other side the facilities wheel chairs, walking aids and baby strollers are good and spacious.

On the whole the hybrids as work place were not experienced as optimal by the drivers near the end of the testing period. Some perceived disadvantages find their cause in the fact that the basic bus – the Citea – is different from the Ambassadors that are common in the Twents fleet. Some are a consequence of the hybrid propulsion and may be solved by further development and some may be inevitable if the potential of the hybrid drive is to be utilized.
As the bus is the everyday working place for the driver some of the feedback received is a consequence of having a very small number of deviating busses mixed in a large, generally homogeneous fleet. A consequence is that all drivers spend very little time on the deviating vehicles In this case maybe only once every month.
A noticeable effect in the drivers' response seems to be that 'opinion leaders' generate a general attitude. When discussed on an individual basis opinions may be much more articulated.

4.8 Noise analysis

The noise was a theme of the project more than one of the program. A problem is that noise is very much determined by characteristics and by the subjective experience of the surroundings and it is very difficult to scientifically measure. When complaints about noise and vibrations came from people in Helmerhoek and even damage to and in houses was reported a specialist analysis of the noise production of one of the hybrids was performed by the University. On the university grounds the bus was analyzed with a 'noise' camera. It showed that both the inlet and exhaust caused relatively high levels.

VDL reengineered the inlet channel and the details of the exhaust system. This reduced the noise significantly. The complaining inhabitants were satisfied and no further issues in this field were encountered.

One of the characteristics that has not shown in the surveys is the behavior of the hybrids when operated fully electrical. Especially with the second generation control software, which made better use of the storage capacity of the supercaps, the hybrids can function with the diesel engine shut off. Especially at the bus stops the busses are very quiet whereas the conventional diesel version is very noisy when accelerating from stand still.

4.9 Monitoring conclusions

In the beginning of the previous chapter the 4 main questions to be answered on the basis of the monitoring program have been listed. The answers are reported in this paragraph.

1. are the reasons for selecting the technology still valid?

In paragraph 2.1 seven reasons were presented for the choice of diesel – electric, serial hybrid as the driveline technology to meet the targets.

- This technology basically is an electric bus carrying its own generator, supplying electric power when fed with diesel fuel. Fuel consumption and emission targets were not reached. The fuel is used by the generator set and this unit also causes almost all emissions.
- Possibility of recuperation of brake energy. As discussed in this chapter most of the propulsion energy is used for acceleration. The option to recuperate (part of) this energy is valuable and the chosen technology is very well suited for this.
- Accelerate by wire was demonstrated in the project. However, it was not shown it can improve comfort.
- Fuel saving and the related reduction of CO_2 were not successfully demonstrated.
- The fuel saving was insufficient to compensate the higher costs of the vehicle.
- It was and is indisputable that the diesel hybrid does not require new or adapted infrastructure.
- At best a limited fuel saving was demonstrated, so the possibility for a meaningful contribution to slowing down oil reserves depletion was not demonstrated.

2. *Was the development of the two buses successful?*

Although the busses were engineered on the basis of an existing and proven type of bus the implemented hybrid drivetrain and all related adaptations were totally new. Still the pilot busses proved very reliable and capable of operating in regular service.

3. *have the technological characteristics contributed to reducing fuel consumption and emissions*

The fuel consumption was roughly identical to that of the - much lighter - diesel driven Ambassadors used in Enschede. The other exhaust emissions were not monitored so no results can be reported.

4. *did the monitoring activities - including the data analysis and interpretation - provide results useful for the project evaluation?*

The technology monitoring activities that were a part of the project gave useful results for project evaluation. Some parameters which would have been useful could not be monitored either because expected sources were not available, because the required costs for additional equipment exceeded the estimated budget or because input from the program was expected (SORT tests) that unfortunately did not materialize.

The stakeholder surveys also provided relevant information for evaluation of the project. Inhabitants of Enschede living near the route of the hybrids, passengers on line 2 add drivers on the hybrids were interviewed asked to fill out questionnaires. Maintenance technicians were spoken occasionally when discussing the maintenance and repair logs. A common finding is that these groups look at the busses from their own primary perspective first and not much from a sustainability perspective. This implies that the pilot busses will be judged negatively if these primary characteristics are not up to standard:

The passengers primarily form an opinion about the bus from a comfort perspective. Their verdict was that the buses were acceptable but not as good as the Ambassadors. The latter are developed for longer distances and are therefore more comfortable for passengers.

The inhabitants confronted with the busses primarily look at nuisance and traffic risks. This is clearly demonstrated by the noise complaints.

For the drivers the bus is their working place. Although they may be professionally intrigued by innovative technology this should provide an improved working space. Negative differences between the new busses and the regular ones cause an overall negative judgment.

The technicians are professionally positive about technology innovation. However, the observation that accessibility of all components in the hybrids was good may well have been their primary filter.

The overall opinions of the institutional stakeholders involved in the project are presented in the next chapter.

5 PERSPECTIVE

A key question after this project is whether the chosen technology is promising from the perspective of the institutional stakeholders involved (the governmental bodies involved, the producers, the user, the university and the managing consultant). This chapter aims at answering this question from the various perspectives. First the findings of the project are summarized as objectively as possible.

5.1 Findings of the project

In the previous chapter the results of the monitoring activities in the project have been reported in detail. For a discussion of the perspective these can be summarized as:

1. Even in this alpha project it was demonstrated that a pilot diesel powered serial hybrid can be developed in a relatively short period of time and that the result is capable to operate well under practical circumstances.
2. The production cost of this type of hybrid is high compared to a modern diesel and due to the complexity maintenance and repair costs will be very likely be higher than that of a straightforward diesel. Fuel saving potential seems limited, thus the operational costs will probably be higher than that of a modern diesel.
3. The innovative buses are acceptable for travelers and for the inhabitants of the city that are confronted with them; it may be assumed that they can be made a good working place for the drivers.
4. In terms of fuel consumption and probably also in terms of emissions and noise the advantages as compared with modern diesels are probably limited. The aim of 50% fuel saving is far away!
5. From the energy analysis it shows that weight is maybe the key parameter for propulsion energy demand. Other relevant factors may well be the efficiency of all subsystems and the increased number of these systems.

5.2 Developments in the market

In the Dutch market the concession system has given a fierce competition which has led to low costs for public transportation. A disadvantage is that the drive for vehicle innovation has basically disappeared. The transport authority is interested in arranging effective public transportation at as low costs as possible. The transportation companies have to meet this demand and will cut the costs of their operation (and thus for the vehicles) as much as possible. The producing industry has to produce high quality busses for low prices. Risks inevitably linked to innovation are avoided. As demonstrated by this subsidy program government stimulation can work wonders.

Emissions are an important driver in the definition of the vehicles used in city centers. At critical locations this has already made public transportation with diesel busses practically impossible in spite of the rapidly more stringent regulations for emissions of vehicles. This development has given rise to the belief that at least at these locations ‘Zero Emission’ is the only feasible solution in the future.

The bottom line is that private cars are easily beaten by busses if people can be seduced to use public transportation. This can be done if comfortable bus transport is offered frequently at low costs.

A scenario may be that development will be that fully electrical operated busses have to be used in City Centers where atmospheric pollution concentrations are close to or even over legally allowed levels and where public accessibility is required. In these parts the distances are relatively the shortest and the network is relatively dense. The balance between energy storage on the busses and energy infrastructure for loading the busses may be favorable for either, depending on the specific location. Further away from city centers hybrids may be a solution for the near future. If zero emission is a demand hydrogen driven serial hybrids may show lower 'Total Cost of Ownership' (TCO) than fully electric vehicles. This depends very much on the cost development of vehicles and infrastructure. The great advantage of fuel powered hybrids is that they can use existing fuel distribution infrastructure and that the vehicles can be flexibly deployed, so in circles where fully electrical operation and hydrogen powered are too expensive there may still be a timeframe presenting feasible operation of improved fuel powered hybrids.

It has been demonstrated that use of heavy vehicles on short start – stop stretches is advantageous for serial hybrids over parallel hybrids. Note that the basis for fully electrically, hydrogen serial hybrid and fuel serial hybrid is an electrically driven bus, so all three can be identical from the electric power supply on. Key factors are the costs compared to diesels and the space required for the energy supply: seats are very valuable on city busses. It is also emphasized that as demonstrated in this particular project that weight increase may eradicate part or all of the fuel saving.

5.3 Perspective of the institutional stakeholders

Ministry and RWS

From the overall goal of the program (contribute to climate and energy targets) and its 'sub goals' (stimulate innovation in public transportation buses; limit 'other' exhaust emissions) this pilot project was relevant to get a better view of the perspective of the diesel powered serial hybrid city bus. As the busses were developed and also tested under operational conditions an improved impression of the perspective has become clear.

As to the main goal - a contribution to the general climate and energy targets - the project demonstrated that the diesel fed, serial hybrid propulsion system used in a public transportation inner city bus is not very promising. The target was a reduction of the energy use by 50%, the result was substantially less and most of the efficiency gain in propulsion energy was consumed by the higher weight and possibly by the increased energy demand of other users on the bus such as additional control equipment and specific auxiliaries required for tasks normally driven directly by the diesel engine. A further possible reason for overestimating the potential is an underestimation of all the energy required for auxiliary equipment on such a bus independent of the drive system.

For the other goals it may be concluded that it was demonstrated that quite a leap in innovation can be made if the design and engineering are done professionally. Unfortunately no results could be reported on the 'other' emissions as these were not specifically monitored.

The regional authority

The regional authority had a number of reasons to take up the project:

- As the responsible authority Region Twente wished to meet the request of the Municipality of Enschede to initiate sustainable public transport for Roombeek.,
- Being responsible for quite a substantial portfolio of public transportation the Region saw the project as an opportunity to increase its insight in innovation options.
- The subsidy program aimed at projects under the responsibility of the authorities responsible for public transportation.

Region Twente is proud of how the project evolved. Apart from all other lessons learned, however, a final conclusion is that the Regions key goal in this field is making sure that effective and efficient public transportation is available to the public. The best way to contribute to the environment for the Region is to get as many people to use public transportation instead of private cars. Of course using the most sustainable vehicles is important but this should serve the key goal. Initiating technology development is far from the core business of Region Twente and can only be done up to a point and may not interfere with key tasks.

The perspective of the technology demonstrated in this project is limited from the perspective of Region Twente: the expected high costs of the vehicles will not be sufficiently compensated for by reduced fuel consumption in order not to endanger the key goal of the Region as mentioned above.

The municipality

Additionally from the program goals the Municipality of Enschede aimed at low noise buses. It's most important goal was to offer innovative and sustainable public transport in Roombeek. The project demonstrated the efforts of the Municipality to live up to its promise to the inhabitants of Roombeek. From the surveys it shows that the inhabitants in and passengers from this part of the city were positive. It is ironic that inhabitants of Helmerhoek complained of noise and vibrations caused by the hybrids in the beginning of the operational phase. After consultation of the complaining inhabitants an technical modifications the issue was resolved..

The Municipality has contributed to technological and sustainable development by participating in the project, is was demonstrated that providing high quality public transportation in Roombeek was seriously sought for and the project demonstrated that the city, Twente and its university are a technology center.

For the perspective of the technology the Municipality shares the view of Region Twente.

The user

Connexxion is one of the main enterprises in public transportation in The Netherlands. Its existence depends in the setting of the concession system on providing public transportation as a reliable and comfortable service. However: this should be done at low costs. Investments in technological innovation of vehicles is therefore not a part of the core business. It was worthwhile to participate in the project as a learning experience in spite of the risk the pilot was for the drivers and the maintenance and repair unit dealing with the Twents fleet.

Testing the pilot hybrids in practice inevitably put the pilot buses between the regular buses used in the Twents fleet. This way in all aspects the hybrids have been seen relative to the 'normal' buses. A disadvantage was that it was difficult to separate the specific hybrid characteristics and the differences between the basic designs (VDL Ambassadors versus VDL Citea's).

Also it was not possible for Connexxion to have dedicated drivers for the hybrids or a smaller team operating these vehicles. As a result many drivers drove the hybrids and always as an exception. This implied they had to adjust to the Citeas every time. That some drivers did not like the hybrids influenced the general attitude towards the buses. On an individual basis the opinions were more detailed as demonstrated in the drivers' survey.

In day-to-day maintenance and repair the vehicles were no different from the regular Ambassadors. For specific attention cooperation with VDL and Vossloh Kiepe worked well.

As for the perspective of the technology The pilot busses proved to be reliable in day to day service, acceptable for passengers, inhabitants living near the route and the maintenance and repair technicians. If a responsible authority would prescribe this type of bus and if the total costs of operating them would not be an issue Connexxion would apply them. However, in the usual competition the costs would be a reason not to seclect these busses.

The producers

The hybrids were based on the existing Citea city bus produced by VDL. The hybrid driveline was developed in close cooperation with Vossloh Kiepe. The control system was mainly developed and delivered by Vossloh Kiepe.
Vossloh Kiepe based its contribution on many years of experience with electric drives for trams and trolley busses. The project was valuable and resulted in improved insights in using supercapacitors for short term storage of electric energy and a very refined control system was developed and tested.
The perspective for Vossloh Kiepe is no further investments in diesel electric hybrid buses, but in electric drives and control systems for all sorts of hybrids and for fully electric busses (either trolleys or battery fed).
VDL was reluctant towards the development of the diesel-electric hybrid busses and only ventured into this field when the government subsidy became available and brought the risks to a manageable level. The project was successful for VDL in a number of ways and it also gave a better insight in developments in the market. During the course of the project it showed that the market became more and more interested in low and zero emission busses.
For VDL it is not yet clear what the perspective specifically for diesel –electric serial hybrids is. The cost of the two vehicles for the pilot project was high. The estimated price if produced in series VDL might fix after beta-testing and further development may be € 300.000,= to € 350.000,=. Whether this is attractive in a future market place depends on many factors. The results of this pilot project indicate that diminished fuel consumption alone will not compensate for the high price.
The expectation is that a part of the market will rapidly swing towards low and zero emission vehicles, particularly for inner city use. In the opinion of VDL these vehicles will essentially have electric drive some with and some without ‘range extender’. VDL is at this moment investing in further technology development based on this expectation.

The University
The university has monitored a number of aspects of the project. Where data were not generated some theoretical modelling was done to increase insight. Also the primary stakeholders were surveyed in order to monitor their experience and acceptance. The mix was a valuable experience for the university and provided the opportunity to involve students.
Unfortunately the perspective of this specific technology in busses is not brilliant, looking at the results. This does not mean that the lessons learnt cannot be valuable from a technology point of view or otherwise.

The managing consultant
From many developments over recent years it has become clear that emissions by vehicles in cities cause unacceptable pollution levels. An increase of the use of public transportation and a decrease of emission of the vehicles would prevent or at least postpone dramatic developments. Serial hybrids could well be the inevitable transition step from the diesel drive generally used now to fully electric and locally zero emission drives in future. The promise of reducing fuel consumption by 50% and at the same time drastically lowering exhaust emissions was very tempting. Once the trust between all participants was there the project developed smoothly: differences of opinion and different views were openly discussed and chosen solutions were accepted and implemented. More could have been learned if more possibilities for monitoring had been available. Possibly a better result could have been reached if the project (budget) had been more flexible enabling adaptation to market developments.
The perspective as shown by the results is very limited. The cost and the weight of the bus have increased so much that operational costs will inevitably be high and the environmental improvements will not compensate for this. The increased weight and the additionally applied materials can only be an improvement from a sustainability point of view if resources management is adapted. It should be noted that adapting this for traditional busses will also result in more sustainable vehicles.

Overall keeping densely populated and utilized city centers attractive requires effective and efficient (public) transportation options. At this point in time electric drive seems inevitable. For development this could be optimize with limited risks. Major uncertainties are in the energy supply:

- on board electric energy storage (short term or long term) or hydrogen/fuel range extenders?
- Infrastructure development (overhead lines, distributed loading, hydrogen)

An important issue is how innovation can be stimulated.

5.4 Key lessons learnt for future development

- With good preparations, thorough design and engineering and careful construction a drastically innovative, but applicable and reliable bus can be built in a relatively short period.
- Weight increase is a major risk when saving fuel for propulsion is an important goal. The reason is that accelerating the bus is the major energy demand; implementing very effective brake energy recuperation tackles only part of this problem.
- In pilot projects the goals should be clearly defined and a monitoring programme should be meticulously developed and executed if it is relevant to understand why the goals are or are not reached.
- If energy consumption is a key factor, monitoring of all energy consumption is important even prior to the design phase, or even before project definition: In this program the focus was on the drive system; easier or meaningful additional options may be found in the (increasing amount of) auxiliaries. Efficiency of all energy consumers on board should be targeted.
- If various technologies are tested in parallel, comparative monitoring is essential if findings from the various tests are to be compared.
- For the passenger the bus is a means of transport. It has to be comfortable and safe. If not it is not relevant whether it is innovative or sustainable.
- For the inhabitants confronted with the bus it has to cause minimal nuisance and not be a traffic risk. Preferable it looks good. Only if these conditions are met it may be relevant that it is innovative or sustainable.
- The bus is the working place for the driver. The quality of the working place should not be less than on a regular bus. Innovative or sustainable is at best relevant after that.
- Target groups (in this project, travellers, inhabitants confronted with the busses, drivers, technicians) have their own ways of judging a bus (see above). In a pilot project these views should be well incorporated.
- Institutional stakeholders have great interests in developments. It is positive if they actively participate in developments and see and respect each other’s position.

6 COLOPHON

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